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The Impact of Future Diesel Emissions on the Air Quality of Large Cities

PEDCo Environmental, Inc, Durham, NC

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The impact of diesel-powered vehicles in the central business districts of New York, Chicago and Los Angeles was studied. Annual particulate matter emissions from automobiles, taxis, buses and light-duty trucks were projected to the year 2000. The emissions were correlated with air monitoring data in order to calculate the impact on air quality. Significant increases were predicted in atmospheric particulate matter because of increased diesel engine use.

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Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
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DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the author, and not necessarily those of the U.S. Environmental Protection Agency.

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TABLE OF CONTENTS

Page

EXECUTIVE SUMMARY 1

1. INTRODUCTION

1.1 Introduction 10
1.2 References 14

2. TRANSPORTATION SCENARIOS

2.1 Problems of Automobiles 16
2.2 Future Scenarios 21
2.3 Projections of Modal Choice 31
2.4 References 40

3. SCENARIOS OF DIESEL SALES

3.1 Diesel Automobiles 43
3.2 Diesel Trucks 47
3.3 Other Vehicles
3.4 References 57

4. EMISSION FACTORS

4.1 Emission Factors in Scenario E_1 58
4.2 References 61

5. METHODS OF ANALYSIS

5.1 Relating Emissions to Ambient Air Quality 63
5.2 Allocating Emissions to Receptor Sites 68
5.3 Monitoring Site Data 72
5.4 Estimates of Population Exposure 77
5.5 Projections of BAP 87
5.6 References 89

6. RESULTS OF ANALYSIS

6.1 The Impact of Future Diesel Emissions 94
6.2 Population Exposure 110
6.3 The Impact of Switching to Mass Transit 119
6.4 Caveats 128
6.5 References 130

APPENDIX A - PROJECTIONS OF MODAL CHOICE FOR THREE TRANSPORTATION SCENARIOS 131

APPENDIX B - DERIVATION OF EQUATIONS FOR α AND β PARAMETERS IN THE CUMULATIVE LOGISTIC DISTRIBUTION FORMULA 150

TABLE OF CONTENTS (continued)

Page

APPENDIX C - TABLE OF PROJECTED DIESEL SALES AND VMT FRACTIONS 153

APPENDIX D - TABLE OF PROJECTED EMISSION FACTORS 170

APPENDIX E - A ROUTINE FOR PROJECTING MEAN ANNUAL TSP 178

APPENDIX F - TABLES OF PROJECTED MEAN ANNUAL TSP AND BAP LEVELS 188

APPENDIX G - PROJECTED TSP LEVELS ASSOCIATED WITH POPULATIONS AT RISK 205

APPENDIX H- PROJECTED TSP CONTRIBUTIONS FROM FOUR MODES OF TRANSPORTATION 208

EXECUTIVE SUMMARY

At the present time, both the government and the automobile industry are expressing considerable interest in diesel engines. The diesel car consumes 25% less fuel than an equivalent gasoline automobile. The diesel engine can meet stringent emission standards for carbon monoxide and total hydrocarbons, and, because of the low volatility of diesel fuels, evaporative emissions are reduced.

On the other hand, the diesel engine emits particulate matter in the form of soot. These particles are very small, with 90% of them less than 1 micron in diameter. For this reason, they are capable of passing into the pulmonary alveoli without being impacted and removed in the upper respiratory tract. Associated with this particulate emission is a wide variety of organic materials. One group of hydrocarbons, the polycyclic aromatic hydrocarbons, contain species that are known to be carcinogenic in test animals. The degree of hazard to humans from these and other organic materials is not yet known precisely. This presents the problem of a pollutant carrying certain amounts of a potential carcinogen into the lungs of the general population, in addition to the negative health implications of the particulate material itself.

This study examines the question of how the increasing use of diesel engines will affect the air quality of the central business districts (CBD's) in our three largest cities: Los Angeles, Chicago, and New York. The pollutant analyzed was total suspended particulates (TSP) in the ambient air. What will be the effect on TSP of switching from automobiles to greater usage of buses and taxis? What will be the effect of the dieselization of the automobile population? Since future events cannot be projected with any certainty, it is the current practice to examine alternative possibilities. In this study future transportation systems and future diesel sales were analyzed in the context of alternative future scenarios.

One set of alternative scenarios dealt with the future use of transportation systems. (See Table 1.) The field of transportation planning was reviewed in order to identify the likely possibilities for using automobiles, buses, taxis, and heavy duty trucks in the CBD of the three large cities. Of special interest were the projected vehicle miles traveled (VMT) for these four modes of transportation, since these are the types of vehicles that generate large amounts of diesel particulate emissions. In the first transportation scenario (T_1), automobile traffic, including light duty trucks, continues to increase in the future much like the trends of the past two decades; bus systems experience growth; and heavy duty truck traffic increases moderately. In the second transportation scenario (T_2) the use of the automobile is moderated so that the vehicle miles travelled by cars do not increase and other systems, such as buses, are used more heavily. In the third transportation scenario (T_3) the use of the automobile actually declines as a result of energy shortages and recessions, or as a result of national policy. Other modes experience growth, but overall transportation demand is dampened.

A second set of scenarios dealt with the future sales and usage of diesel engines. In the first diesel sales scenario (D_1) it was assumed that the diesel engine would remain an insignificant fraction of the total automobile population. In the second diesel sales scenario (D_2) it was assumed that diesel automobile sales would accelerate through a rapid growth phase, reaching 25% of total car sales by 1985. This rate of increase is described in a mathematical model which shows the diesel engine reaching nearly complete dominance of the automobile market in the early 1990's. Dieselization of the heavy duty vehicle population was assumed to continue in a similar pattern, following recent trends.

At the present time, the exact rate of particulate emissions from future diesel automobiles is not known. Therefore, the emission factors used in previous studies were used, but treated

Table 1. SUMMARY OF SCENARIO COMPONENTS

Symbol	Name	Description
	Alternative Transportation Scenarios	
T_1	Optimistic Growth	Continued growth in automotive VMT following recent historical patterns; modest growth of bus, taxi, and HDT modes in central cities.
T_2	Moderation	Zero growth of automotive VMT coupled with partial modal shift to bus and rail transit; modest growth in taxi and HDT usage except in Chicago.
T_3	Automotive Decline	Decline in automotive VMT due to economy or government controls; modest growth of bus usage; decline of taxi and HDT usage.
	Alternative Diesel Sales Scenarios	
D_1	No Diesel	Diesel engine remains an insignificant part of the automobile and taxi populations; use of diesel in buses and HDT's follows historical growth pattern.
D_2	Full Scale Dieselization	Diesel engines gain rapid acceptance, becoming the predominant engine in cars and taxis in the 1990's; use of diesel in buses and HDT's follows historical growth pattern.
	Alternative Emission Factor Scenarios	
E_1		Emission factors from previous studies were used.

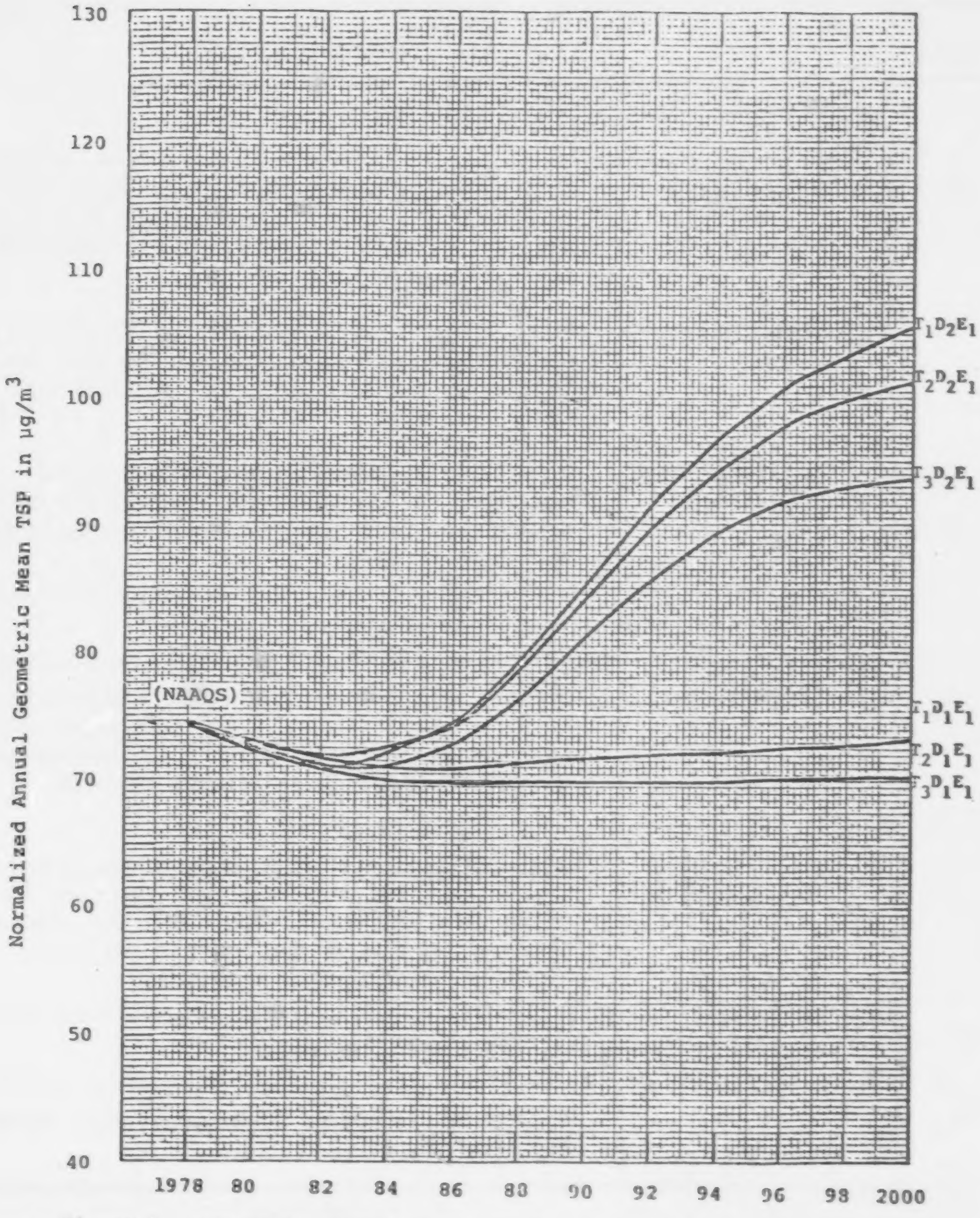

Figure 1. Projected Annual Mean TSP for N.Y. Monitoring Site at 170 E. 121 St.

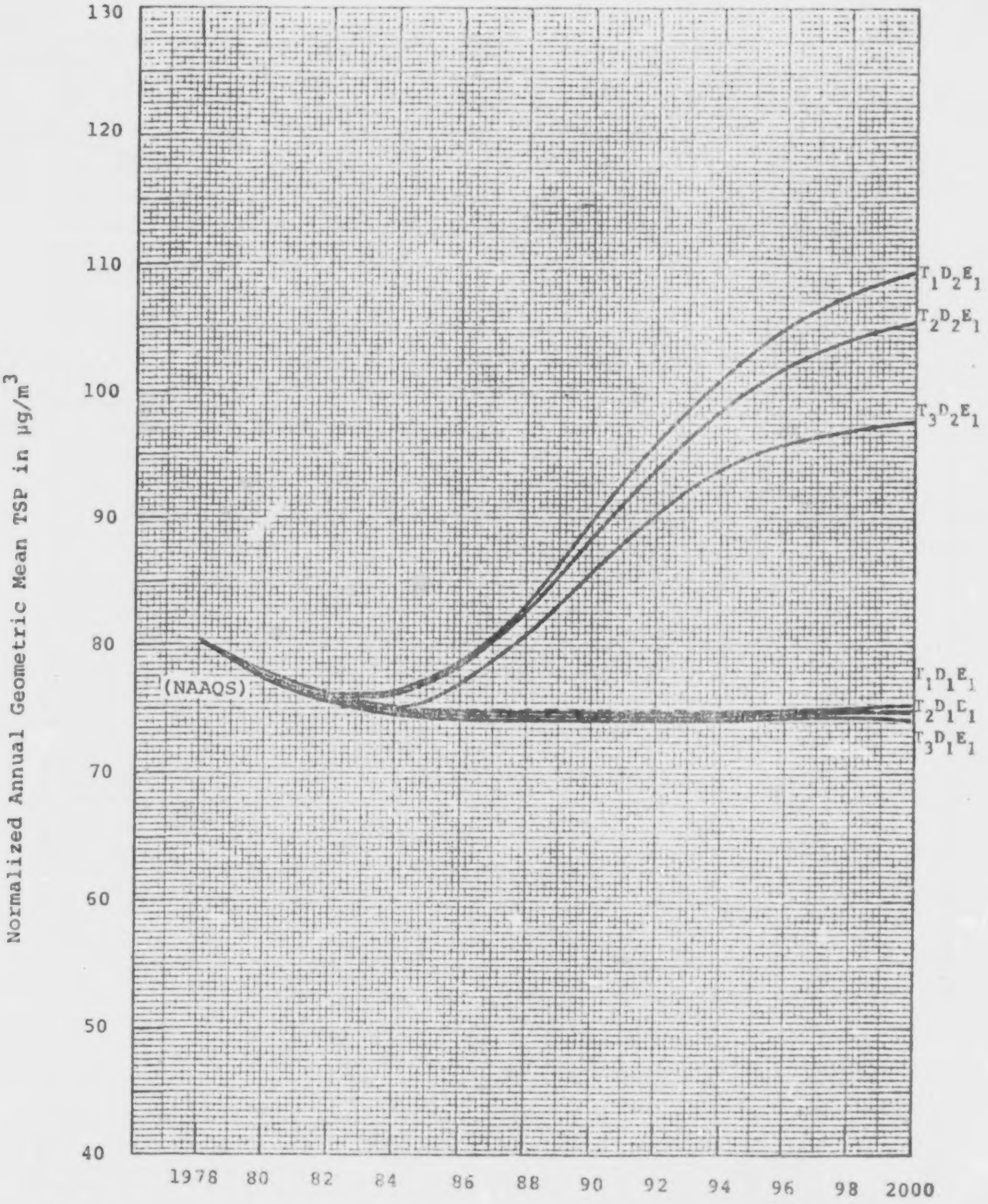

Figure 2. Projected Annual Mean TSP for Chicago Monitoring Site at 1947 W. Polk.

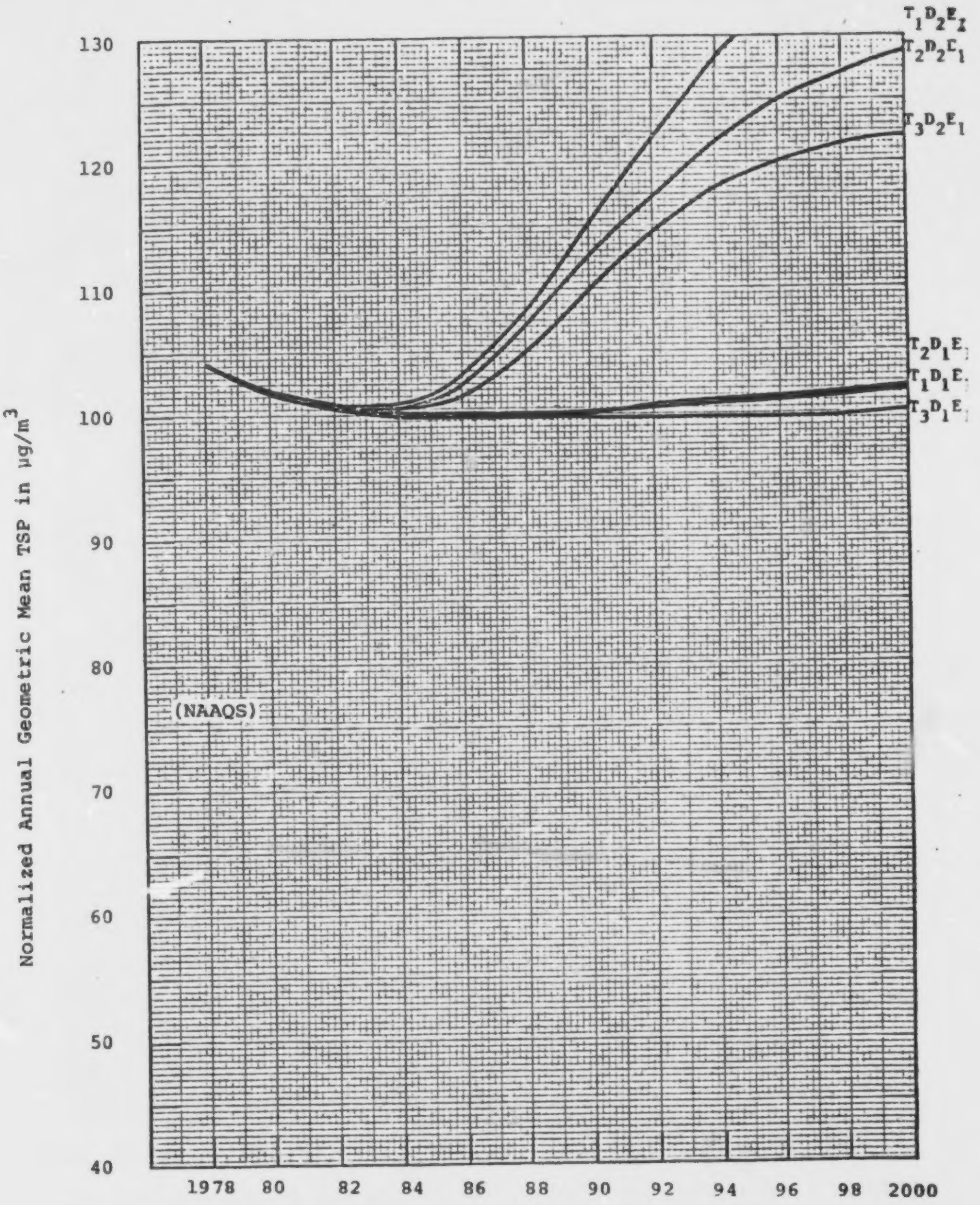

Figure 3. Projected Annual Mean TSP for California Monitoring Site at 434 S. San Pedro St.

as a scenario option (E_1). This allows for updating the study as newer emission factors become available.

A relatively new method was used to project future ambient levels of TSP. The relationship between transportation emissions and ambient levels of TSP was determined by trace element studies, rather than using an area-wide computer model. First, 16 air quality monitoring sites were selected from the central business districts of the three cities where the impact of diesel exhaust was expected to be most severe. Second, the fractions of TSP emissions that are attributable to vehicles and that were effective at given monitoring sites were measured by trace element studies carried out by other investigators in New York and Los Angeles. Third, air quality data for 1975 through 1977 were combined into a standard base year. This procedure was patterned after the normalization of data for a standard meteorological year. Fourth, all non-transportation TSP emissions were held constant, so as to examine only the effects of various transportation policies or dieselization policies. Thus, the results of the study should be viewed as an analysis of policy alternatives, and not as a forecast of actual TSP levels. The results were expressed in terms of population exposure as well as ambient TSP. Levels of benzo(a)pyrene were also projected.

The projected TSP levels varied according to what scenarios were analyzed, as shown in Figures 1, 2, and 3. The largest effect was found to be the effect of different scenarios of diesel automobile sales. In the non-diesel scenarios (D_1) the ambient TSP at all monitoring sites remained at or below the present levels. In the rapid dieselization scenarios the ambient TSP levels at all monitoring sites increased dramatically after 1985. The amount of increase ranged from 17 to 41 percent, depending on which site and which transportation scenario were analyzed.

The effect of rapid dieselization of the automobile population with present emission factors would have a substantial effect on the CBD residents in these three cities. Figure 4 shows

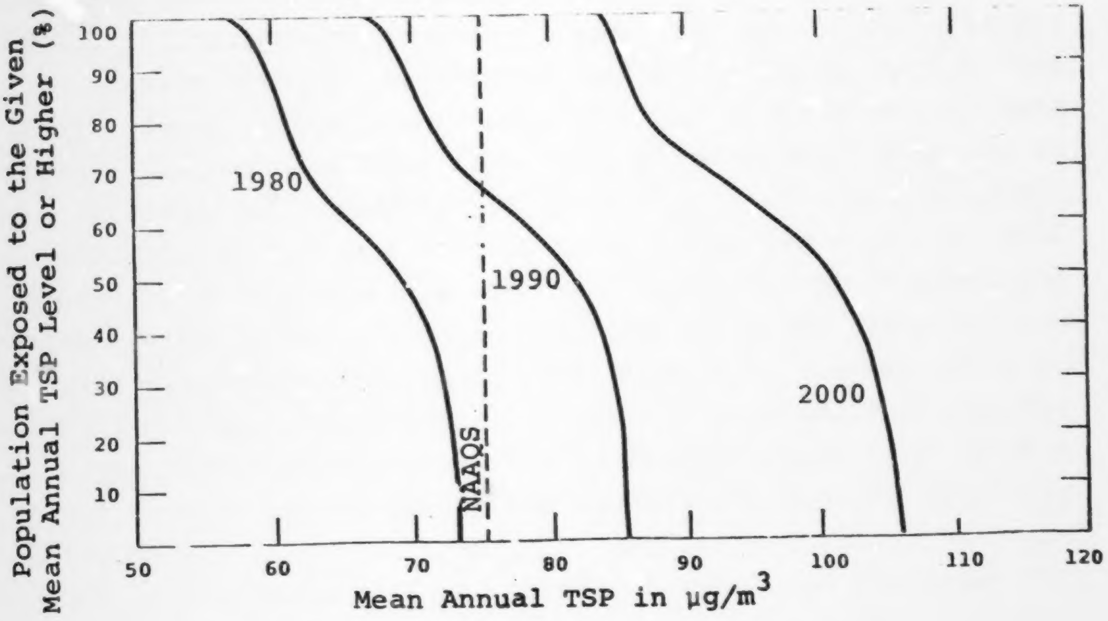

Figure 4. Projected Increase in Manhattan Island Population Exposed to TSP in Scenario $T_1D_2E_1$.

the increased exposure of the Manhattan Island population under rapid dieselization with continued growth of automobile usage. At the present time, the entire population is exposed to TSP levels that are less than the primary national ambient air quality standard. With rapid dieselization 65% of the population could be exposed to TSP levels exceeding the standards as early as 1990. By year 2000, the entire population would be exposed to levels substantially in excess of the present standards.

In the event of rapid dieselization, the extent of automobile usage would determine the ambient TSP levels actually reached. Figures 1 through 3 show that the effect of reduced auto usage in scenarios T_2 and T_3 is to ameliorate the levels of TSP reached by year 2000.

The impact of switching from heavy use of automobiles to the increased use of bus and rail transit is a net improvement in projected TSP levels. It was found that a large reduction in the TSP contribution from the automotive mode of transportation correlated with a very minor increase in the TSP contribution from buses. This is primarily due to the large capacity of buses, which can accommodate 40-100 commuters in scenarios involving a modal shift. The VMT of automobiles can be reduced by about 50 miles for each 1 mile increase in bus VMT experienced in a modal shift. Despite the higher TSP emission rates for buses compared to automobiles, their use for commuting contributes to a significant reduction in TSP contribution from the transportation sector in the central cities. In all scenarios, contributions from buses represented a significant portion of future ambient TSP levels.

Unlike buses, the impact of taxis closely parallels the impact of automobiles. Dieselization of taxis is expected to follow the same pattern as automobiles; the proportion of diesel engines is assumed to be about the same in both taxi and auto populations. A weakened economy is expected to reduce the usage of taxis, but taxis are much less affected by a modal shift than are automobiles. If taxis become dieselized, then the contribution from the taxi mode will represent a significant portion of the ambient TSP levels.

It is worth observing that the effect of dieselization will not be felt until after 1985. All scenarios show a continued improvement in TSP until this time, which reflects the decreased use of leaded fuel.

1. INTRODUCTION

1.1 INTRODUCTION

At the present time, both the government and the automobile industry are expressing considerable interest in diesel engines. The Department of Energy (DOE) and the National Highway Traffic Safety Administration (NHTSA) are interested in the use of diesel automobiles because they consume approximately 25% less fuel by volume than equivalent gasoline-powered engines. NHTSA has projected that the implementation of a 27.5-mpg fuel economy standard in 1985 could result in a possible savings of 3 1/3 billion barrels of oil by the end of the century, or about one-third of the Alaska North Slope oil reserves.[1] General Motors Corporation has intentions of introducing diesel engines into its lines of automobiles. At present, the Oldsmobile has a diesel option, and a decision to convert more lines to diesel may be forthcoming in the near future.[2]

The diesel engine may offer some advantages for the control of air pollution. First it can probably meet stringent emission standards for carbon monoxide and for total hydrocarbons. Second, because of the low volatility of diesel fuels, evaporative emissions are reduced. Third, diesel engines have been said to have superior durability. Over a 100,000 mile lifetime, emissions are claimed to increase only slightly.[3] For the presently regulated pollutants, the diesel may represent a technical improvement in emission control.

On the other hand, the diesel engine represents a new spectrum of pollutants with an unknown level of possible hazards. During the combustion cycle, current diesel engines create a wide range of hydrocarbons, more than 20,000 individual species.[4] These compounds represent the combustion products of fuel and lubricant, with hydrocarbon molecules ranging in size from C_1 to about C_{40}. The compounds of greatest concern are those responsible for positive results on the Ames Test. This includes classic polyclyclic materials, such as benzo(a)pyrene, but also includes other materials that show positive Ames activity, which at the present time have not been precisely identified. Thus, while the amount of hydrocarbon emissions may be small, there is concern for the release of potential carcinogens at any concentration.[5]

Another possible problem to overcome is that of particulate emissions associated with diesel exhaust. While gasoline engines typically discharge little particulate matter (if they burn unleaded fuel) the diesel engine combustion process emits substantially more particulate matter. The amount of particulate material currently emitted from diesel cars and light trucks ranges from about 0.2 to 1.0 grams per mile. (See Figure 1-1.)

DIESEL CAR	ENGINE DISPL (L)	TEST WT (LB)
A	1.5	2250
B	2.1	3000
C	2.1	3000
D	3.0	4000
E	5.7	4500

GASOLINE

PREREGULATION, LEADED FUEL

CURRENT PROD., NO LEAD & CONV.

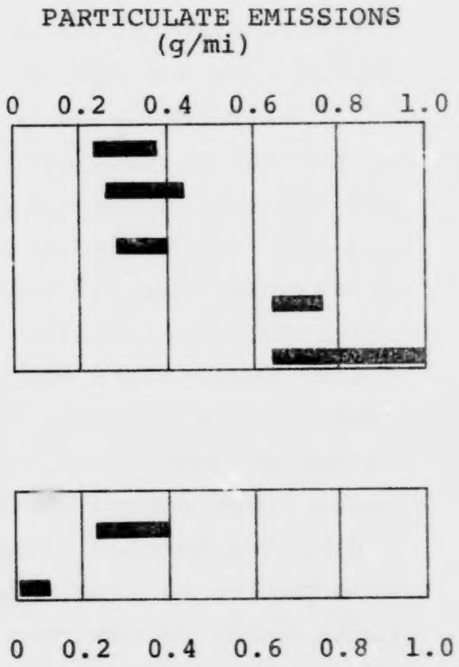

Figure 1-1. Passenger Car Particulate Emission, 1975 Federal Test Procedure.[4]

Furthermore, it has been found that diesel particulates are quite small in size, with 90% of the particulate mass less than 1 micrometer in diameter. This is a particle size that is generally considered respirable. They are capable of passing into the pulmonary alveoli without being impacted and removed in the upper respiratory tract.[7] This presents the problem of a pollutant (diesel particulates) carrying potential carcinogens into the lungs of the general population.

The Environmental Protection Agency is actively investigating the potential problems of diesel engines. It has begun an extensive research program to determine the degree of hazard involved in diesel exhaust. The health effects research involves exposing test cultures and organisms to diesel exhaust residue from a variety of sources. Test procedures are being developed to standardize the methods of analyzing emissions. Other studies are examining the variations in emission products with various engine configurations and operating conditions.[8]

The study presented in this report examines the question of how the increasing use of diesel engines will affect ambient air quality in our three largest cities: Los Angeles, Chicago, and New York. Recognizing that some gaseous emissions may actually be reduced, most of the report is devoted to analysis of total suspended particulates (TSP) in the ambient air. Increased diesel particulate and emissions of polycyclic organic material (POM) can be expected from two possible sources. One is the switching from gasoline to diesel engines in automobiles and taxis. The second is the increased use of heavy duty diesel trucks and buses. If there is a strong effort to switch from automobiles to mass transit, then the emissions from buses and taxis might be expected to increase. Such an increase must be balanced against the reductions in automotive emissions.

The impact of diesel exhaust on the air quality of the cities will depend upon certain unknown factors and future events. Future events to consider include the type of transportation system changes that are made, the availability of fuels, the health of the economy, and the introduction of particulate standards for mobile sources. Some of the unknown factors that may affect emission levels include the emission factors that can be expected from future model years and their rate of deterioration over the life of the vehicle.

Rather than projecting a future trend, it was considered desirable to look at alternate future scenarios. Such methodology has become the accepted practice, not only in examining environmental impacts of governmental actions, but also in planning desirable transportation systems.[9] In order to analyze the various factors that determine the impact of diesel engines, future scenarios were developed as follows:

1. Transportation Scenarios (Chapter 2) - The recent literature on transportation planning was reviewed and the likely features of future transportation systems were examined. The types of systems utilized in the future will have a direct bearing on the vehicle miles traveled by various vehicle types in central cities. These scenarios were used to analyze the effects of modal split and the intensity of transportation usage on the levels of TSP. Of special interest is the increased use of diesel taxis and buses in the central city.
2. Diesel Sales Scenarios (Chapter 3) - Whether or not diesel engines are introduced into the automotive population by American manufacturers will have considerable impact. A mathematical model was developed to describe a rapid diesel introduction scenario, and the resulting diesel engine distribution in the automobile population was described.
3. Emission Factors (Chapter 4) - The present production line diesel engines have been tested and their emission factors calculated. Deterioration factors for the aged vehicle population have not been determined, and future engines may have different characteristics than those presently being tested. Emission factors from a previous pilot study were utilized as one emission scenario for the present study.

Analyzing the impact of diesel in three large cities under the limits of the resources available in this study presented a significant challenge. The cost, capabilities, and limitations of atmospheric dispersion modeling were studied, and an alternative method of analysis was developed in Chapter 5. The methodology is based upon the use of trace element studies to determine the proportion of total suspended particulate (TSP) emissions at a monitoring site that are attributable to motor vehicles. It is also based upon normalizing the base year emissions data to a standard meteorological year; the projection of future air quality levels assumes standard meteorological conditions for each projection year. The use of this methodology permitted the examination of the effects of future diesel exhaust emissions on the particulate (and related hydrocarbon) levels in the CBD of three large cities. The results of this examination are presented in Chapter 6.

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2. TRANSPORTATION SCENARIOS

2.1 PROBLEMS OF AUTOMOBILES

In the Clean Air Act of 1970, Congress anticipated that an automobile emissions control program alone would not be sufficient to achieve the air quality standards in all cities. Where monitoring data showed that the control of stationary sources and the control of automotive emissions were not sufficient, additional steps would be required. Each State was to submit a State Implementation Plan (SIP) which would show how the National Ambient Air Quality Standards (NAAQS) were to be met within each Air Quality Control Region (AQCR).[1] It was expected that the use of automobiles would have to be reduced in some areas.

In response to the need for transportation planning, EPA conducted a series of studies in thirteen cities to provide assistance to the States in formulating strategies to reduce the use of automobiles. Measures to reduce automobile usage would be aimed at curtailing the vehicle miles traveled (VMT). Such measures might include improvements in transit systems, implementation of carpool programs, priority treatment for buses on streets, restrictions on parking, or some "disincentive" to the use of the automobile.[2]

The use of automobiles in transportation has been growing since automobiles first became available to the public. Intracity mass transit, on the other hand, has been declining for the last 50 years, except for a period of gasoline rationing during World War II. In 1950, roughly 17% of urban trips were by transit, whereas by 1965 it had declined to 5%. In 1975 it dwindled to 2.5% (see Figure 2-1). The continued population growth and prosperity during this century has increased the demand for automobile travel and decreased the necessity of using the less expensive modes of travel such as bus and rail transit.[3]

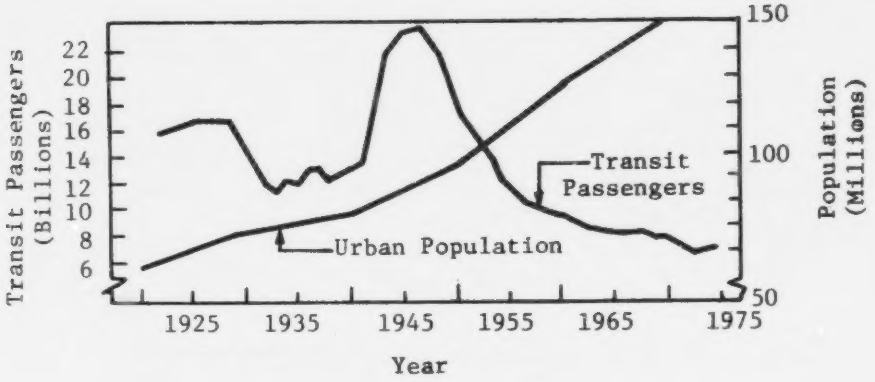

Figure 2-1. Trends in Transit Passengers and Urban Population, 1920-1975.

Leahy[4] points out that the preference for the use of the personal automobile has a rational basis in an expanding economy. First of all, the door-to-door travel time for cars is less than that for transit systems. Second, the service is available whenever it is wanted. Third, the modern automobile is very reliable and provides a high degree of personal comfort, even luxury. Fourth, the automobile user feels more secure from criminal attack than does the transit rider, particularly in late evening hours.

Air pollution is not the only problem of the automotive preference. Personal vehicles are presently consuming more than 50% of the energy used in transportation and about 25% of the petroleum being consumed in the United States. Leahy has critically examined the current projections of automobile usage and their implications for future energy demand. He and others have pointed out that projected energy requirements would exceed U. S. energy production by an increasing amount in the future (see Figure 2-2). He showed the effects of various projections of transportation energy usage, including an extreme modal shift (30% use of electric car and 15% use of diesel bus). He found that even this shift would be insufficient to close the gap.[4] It is apparent that there is a need for reducing petroleum demand as a matter of national interest.

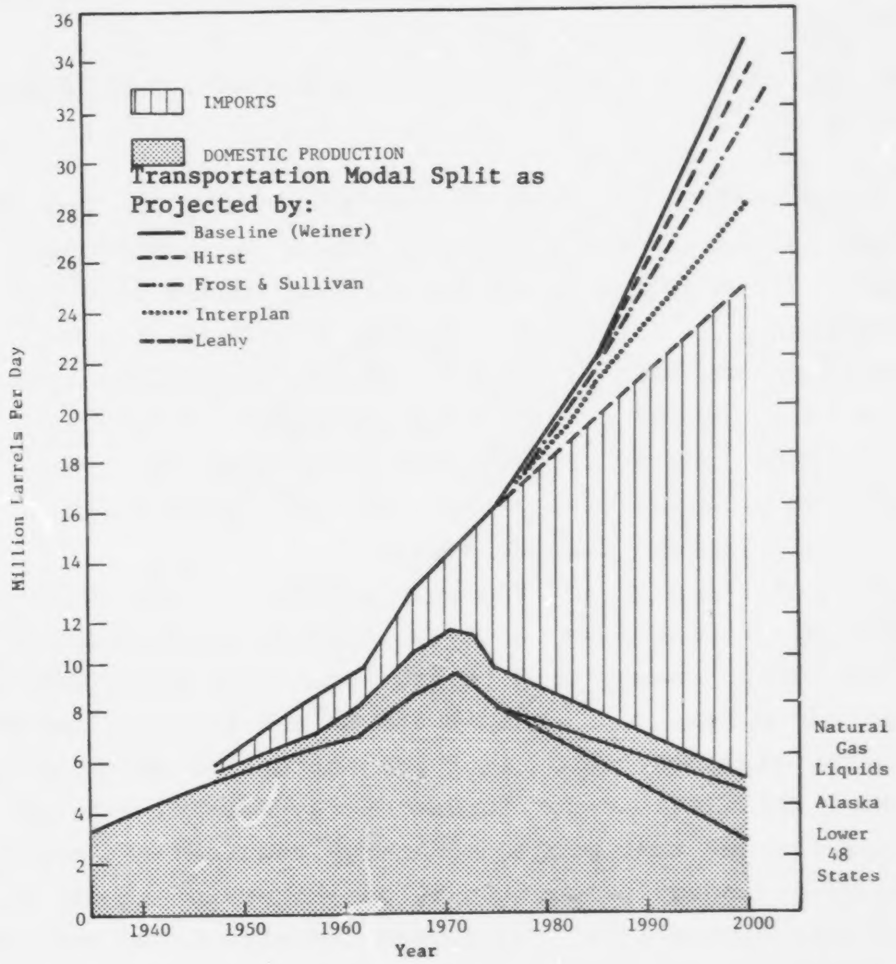

Figure 2-2. Effects of Five Different Modal Splits on U. S. Petroleum Required Supply.

Holder[5] has pointed out the energy efficiencies of various modes of travel (see Figure 2-3). Energy consumption by any one of these modes is a function of the energy efficiency of the system and trip demand on the system. Energy efficiency can be improved by increasing the density of use (persons per vehicle per trip). The determinants of trip demand are population and the number of trips per person. From a national or regional perspective it is desirable to increase energy efficiency by increasing the number of persons per vehicle-trip and by shifting to the modes of transportation that have the greater passenger capacities. Despite the obvious need, there are wide differences of opinion on how much modal shift will actually occur in the future.

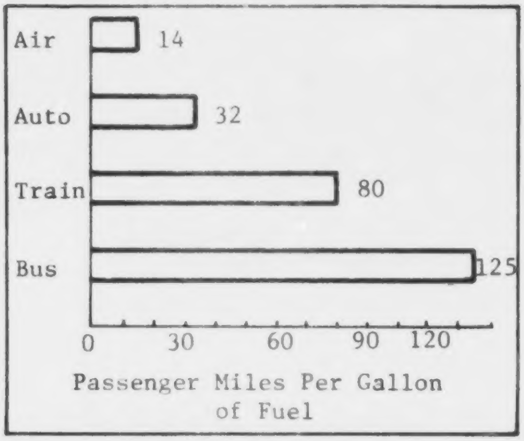

Figure 2-3. Energy Efficiencies of Intercity Passenger Transportation Modes[5]

The three cities examined in this study vary widely in the types of urban transit systems presently being used. New York City has perhaps the most extensive system of buses and subways in the country. This has come about partly as a matter of historical accident.[4] New York was the first large city in the United States, and the need for urban transportation was felt in the 19th century before the personal automobile became the dominant mode of transportation (see Figure 2-4). Subway systems were built early and carried over into the present era. High capital costs and the slackened demand for such systems make the further construction of them unlikely except where they are highly subsidized. About 23% of the daily passenger miles in the New York City Standard Metropolitan Statistical Area is accommodated by rail and about 4% by bus transit. Like New York, Chicago is also an older city and has a rail transit system in place. About 23% of the daily passenger miles are by rail and about 5% by bus.[6] Los Angeles, by contract, has developed almost entirely in the twentieth century and has experienced much of its rapid browth after WW II, when the race to automobiles was in full acceleration. As a result, the city has no subway system, and only about 2% of current passenger trips are accommodated by bus.

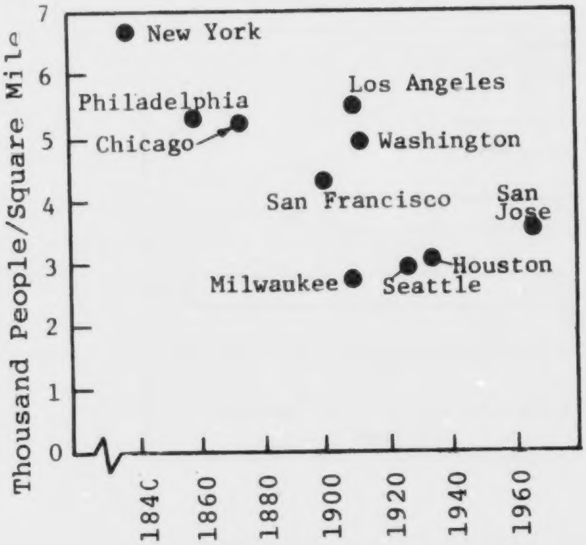

Figure 2-4. The Year Each Center City Passed 350,000.

Rail transit systems may seem obsolete, but their presence in urban areas will determine how readily these cities can accommodate an era of reduced petroleum supplies. It was found during the energy "crisis" of 1973 that the people in New York simply shifted their mode of travel in the city and were less immediately affected than those who did not have ready access to mass transit. This does not mean, however, that mass transit is the preferred mode of travel when the economy is experiencing a boom fueled by unrestricted foreign oil imports.

2.2 FUTURE SCENARIOS

A number of different projections of intracity modal split have been proposed in recent years, based on alternative future scenarios. Perhaps the most extensively documented scenarios are those worked out by Stanford Research Institute (SRI). Curry et al.[7] detailed four possible futures for 1995 and 2025. Their analysis was based upon energy reserves, economic conditions, and society's values.

> "The first scenario, "Success", is a story of competent management, consensus, and technological ingenuity. The United States continues to move toward rising affluence--so that by the year of 2025 the "post industrial society" is a reality. It is a world of high technology, sophisticated communication, rapid mobility, and high levels of consumption. It is the fulfillment of the traditional American Dream."[7]

The Success scenario depends upon a continued expansion of energy supplies, not only oil but also alternative fuels as they are needed. Projections of automobile usage derived from this future are similar to the conventional projections of highway planners. Growth in the next 20 years is treated as a continuation of the growth rate experienced over the past 20 years. Changes in energy costs and personal values are not usually taken into account.

> "If, on the other hand, our resources and managerial capabilities fall short of requirements, our technology is not successful soon enough, and our opinions about solutions are deeply divided, then the next 20 years are likely to be a time of deepening recession, eventually reaching a depression called Distress. The progress downward will be in small increments, unlike the collapse of 1929. By 1995 the resulting situation--a fragmented society struggling to get by--could not persist."

> "We have posited two alternative paths out of the depression, so Distress becomes the first 20 years of two full 50-year scenarios. Recognizing that managing a divided and unruly society is impossible, people could in their frustration come to accept the need for a tightly Disciplined Society, whether by choice or by compulsion. The result would be the sacrifice of many freedoms and much diversity to the constraints imposed by an authoritarian technocracy. This bureaucratized leadership, faceless and diffuse, would have at its disposal so-

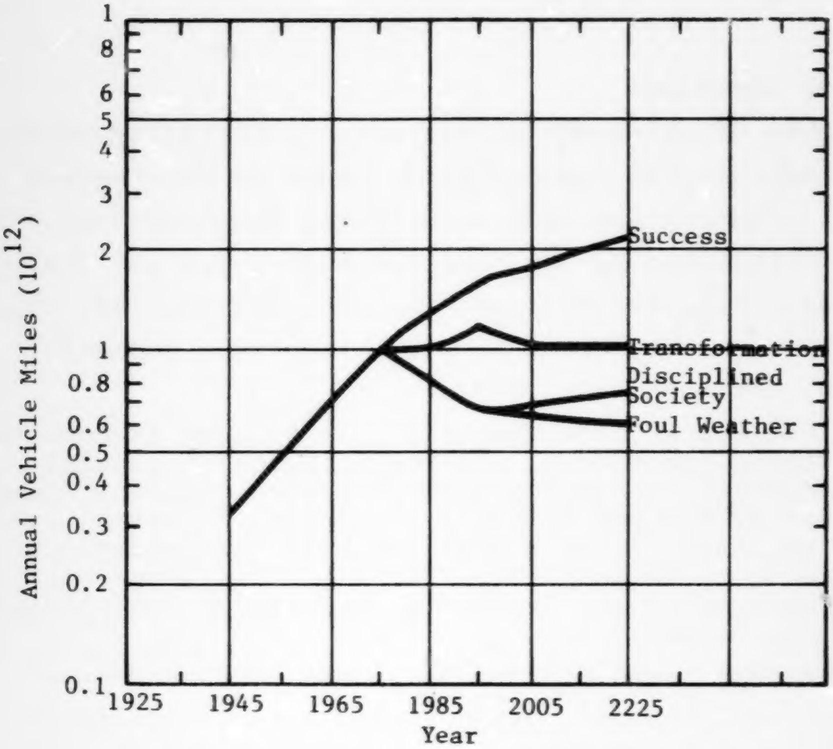

Figure 2-5. Automobile Vehicle Miles Traveled in SRI Scenarios.[a]

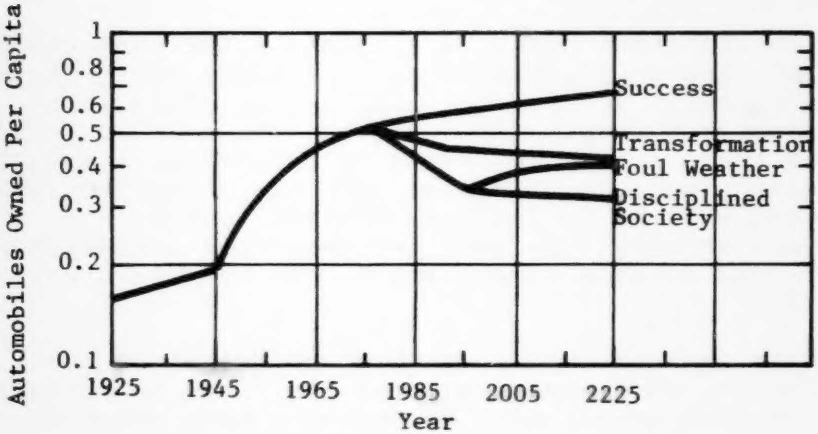

Figure 2-6. Per-Capita Automobile Ownership in SRI Scenarios.[a]

[a]Source: Reference 7.

> phisticated psychotechnology and advanced social engineering capability. Most people under this scenario would still want the material rewards of economic success. They would be willing to overhaul the institutional fabric of society and to endure severe constraints on their freedom--including their freedom to travel--to obtain that abundance."

> "If, however, in the face of that depression, the nation had to face a unifying crisis as it did in World War II, then it might not turn to authoritarianism. In this scenario, *Foul Weather*, the climate takes a turn for the colder and drier--the winter of 1976-1977 becomes typical. Very large numbers of people are forced or attracted to move to the South and Southwest to escape undesirable climate and follow industrial relocations. Agriculture is especially hard hit and the need to preserve farmland pushes cities in the direction of increasing density. However, the need for adaptation and reconstruction for survival have brought about slowly rising affluence and an unsurpassed degree of unity."[7]

The disciplined society scenario brings to mind an authoritarian regime that regulates life in the United States in a manner that conflicts with our traditional values of individual freedom and possibly with the Constitution. This alternative was rejected for analysis in this study because it was deemed unlikely that values would change in this direction. This study is biased in the direction of examining the more moderate possibilities rather than disaster planning.

The foul weather scenario presumes a change in the continental climactic pattern in the short space of 50 years. While speculation about trends in the weather is popular in some circles, historical climatological data does not necessarily require such a projection. The severity of recent winters is within the normal range of fluctuation over the period of weather recording. While the foul weather scenario is a refreshing contrast to the conventional wisdom, it is a future alternative that we have chosen not to analyze.

Another scenario of the SRI report was considered important to this study. Curry[7] presents the case in this manner:

> "Clearly the *Distress* scenario and its two successors are undesirable. Given the present dominant set of values, the Nation would opt for *Success*. We cannot, however,

Table 2-1. FOUR SCENARIOS OF MODAL SPLIT BY SRI

City	Mode	Daily Passenger-Mile Estimates by Scenario (1,000's) Year 2025				
		Present	Success	Foul Weather	Disciplined Society	Transformation
New York	Auto	128,311	174,043	72,140	54,741	85,671
	Bus	5,227	15,949	12,419	34,155	14,547
	Rail	29,042	22,926	24,847	38,419	25,534
	Total	162,580	212,918	109,406	127,315	125,752
Los Angeles	Auto	110,648	137,922	100,327	31,919	68,382
	Bus	2,683	7,088	15,346	38,362	7,516
	Rail	0	20,593	24,318	39,951	18,258
	Total	113,331	165,603	139,991	110,232	94,156
Chicago	Auto	96,642	98,829	45,927	30,612	49,141
	Bus	4,620	10,505	11,220	27,934	11,781
	Rail	22,120	20,350	26,544	40,827	21,500
	Total	123,382	129,684	83,691	99,373	82,422

Source: Curry, David et al., Transportation in America's Future: Potentials for the Next Half Century, Part I - Societal Context, DOT-TPI-77-21-1, (PB 270467/4GI), June 1977.

> assume a frozen set of national values when they have not remained so in the past and are not held unanimously even now. If the present mix of values changes dramatically, the kind of society that results will be significantly different. In the Transformation scenario, coping with the problems of the future is greatly eased by growth in the popularity of a way of life that we call "voluntary simplicity." It values frugality, simplicity, harmony with nature, and inner spiritual development. As more and more people adopt that way of life, some of the problems become easier to solve--the need to provide economic growth is not as great, energy demand does not grow as quickly, and a preference for part-time employment reduces the need for jobs. By the year 2025, the result is a highly decentralized but bifurcated society with a slight majority pursuing this new way of life and nearly as many successfully striving to achieve the abundant life style of the Success scenario."

The changes in values reflected in the Transformation scenario are credible, especially since smaller changes of this nature were evident in the 60's and 70's. Such an alternative future, while less drastic than some other SRI views, means an actual decline in energy use. It provides a scenario in which the central city automotive VMT may be reduced by consensus politics operating at the local level. It presents the possibility of meeting air quality standards through a change in life styles. The automotive decline projected in this scenario could be brought about by federal or state laws requiring a substantial shift to alternative modes of transportation. While the political consensus to support such a forceful policy may be lacking at the present time, it is useful for regulatory officials to examine the results of the possible application of such a policy. For this reason some of the SRI data for this scenario has been used in this study.

The assumptions underlying these scenarios affect the use of intracity mass transit in a way that has been analyzed in detail by SRI, but will not be repeated here. However, the results of their analysis are presented in Table 2-1. It will be noted that each of the alternatives except one foretells a considerable reduction in the use of automobiles. The scenario "success" shows a continued expansion of vehicle use which is similar to short-term projections used by highway planners.

On the other hand, an energy-constrained future seems to be the most popular view among professionals at the present time. For example, a recent workshop was held in the Chicago area to discuss alternative transportation futures. In this conference there was a strong consensus that energy scarcity was the appropriate scenario, while energy abundance was considered unrealistic. In the energy "scarcity" scenario from this conference, petroleum prices would double or triple in terms of constant dollars by year 2000. Automobiles would become more efficient and some would switch to non-petroleum fuels. Despite technological breakthroughs, mobility would drop by 15%, particularly as it is reflected in the VMT of personal automobiles. There would be a move toward higher density housing patterns and greater acceptance of public transit.[8]

By contrast, the short-term planning projections currently being used in transportation planning show increases in the total VMT by automobiles. Koppelman[9] has reviewed the projections of various researchers and examined various assumptions underlying the forecasts (see Figure 2-7).

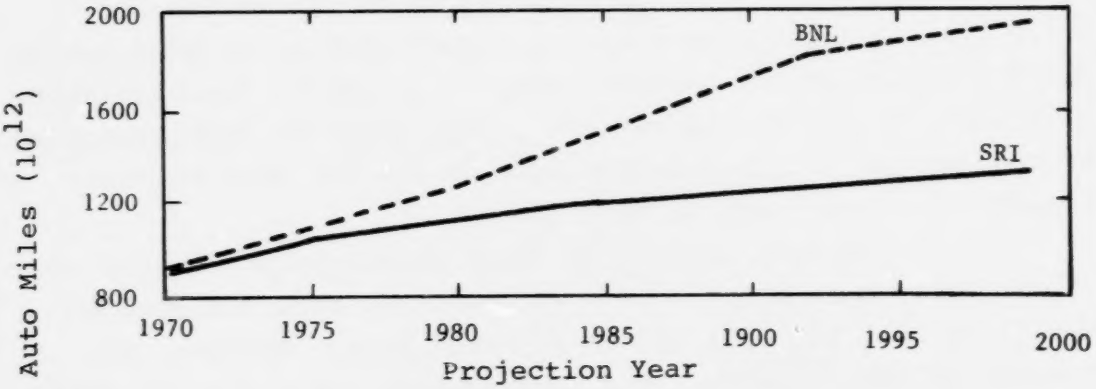

Figure 2-7. Alternative Projections of Annual Automobile Miles.

Apparently, the short-term forecasts of automobile usage are not as energy-constrained as some of the longer range views.

Some researchers believe that the demand for auto travel will continue to increase in the future. In some projections the U.S. population is expected to increase by as much as 41.8% from 1972 to 1990, while the amount of urbanized land area is expected to increase by 83% with a concomitant 20% decrease in urban density.[4] If these projections were realized, it would mean intensified suburbanization, with the distances between destinations growing longer. Such a land-use pattern would increase dependence upon the automobile, and the feasibility of mass transit systems would be in doubt. The demand for auto trips would cause the number of automobile passenger miles to increase by a factor of 1.75.

In view of differing opinions on this subject, it was necessary to develop a new set of alternative scenarios to use in the present study. These scenarios take into account varying ideas about energy availability, government response, and the public's changing perceptions of transportation needs.

2.2.1 Optimistic Growth (Scenario T_1)

In Scenario T_1 the trends of the past are generally projected into the future. The number of licensed drivers and the number of automobiles continues to increase at a fixed rate. The number of trips and the miles driven per trip continues to increase. Suburbanization continues to represent the predominant form of growth, and the density of urban places decreases. Recent actions of the OPEC Nations notwithstanding, the price of oil and the pumped price of gasoline increase at a rate less than the rate of inflation (decrease slightly in real dollars). The U. S. economy continues to be strong.

In Scenario T_1, the automotive VMT in the urbanized places continues to increase following past trends. The current projections of government agencies are used to project VMT; where these projections are not available, the data from the SRI scenario "success" are applied. The modal split experienced in the recent past continues in the future, with increases in the automotive share. Efforts to regulate modal choice for purposes of fuel conservation or reasons of air quality continue to fail. Although air quality begins to deteriorate after emission controls are fully effective (1985), the populace is satisfied.

2.2.2 Moderation (Scenario T_2)

In Scenario T_2 the price of oil (and gasoline) increases at an annual rate roughly equal to the rate of inflation, following recent trends. Such a development could be caused by the actions of OPEC Nations or it could result from a national energy program. The price of oil begins to reflect declining U.S. oil production and the increased cost of developing the more remote reserves. The U.S. economy grows at a slower rate than that experienced after World War II. Recessions occur more frequently and the rate of real growth is less than 1-1/2%. As a consequence, the use of automobiles is projected to decrease at a rate which offsets the VMT increase projected in Scenario T_1 that is, the urban VMT of automobiles levels off at the present rate. As the population continues to grow moderately, adjustments in trip-making take place in the following manner:

1. More persons join carpools aided by government incentives.
2. More persons desire to ride the bus or subway rather than put gas into the family car.
3. Fewer young families can afford a private home and therefore live in apartments near work and shopping facilities. Communities increase the stock of apartments.
4. More families purchase new homes near work.
5. National and local governments continue to invest in modest transit improvements.
6. More business firms move to suburban communities near employee residences.
7. Research is conducted into the processing of alternative fuels.

In Scenario T_2 automobile VMT is projected at a zero growth rate. The growth of heavy duty diesel trucks serving the central city is slowed, but the growth rate does not reach zero because business activity continues to grow and trucks are used to haul goods. As fuel prices increase, the cost of transporting goods is passed along. While families and individuals reduce the number of non-essential trips they make, business hauling is determined by the volume of economic activity. Moreover, trucking does not compete directly with rail in most of the central city. Therefore, in this scenario truck VMT is projected at a reduced, but non-zero, rate of growth. Scenario T_2 is an artifact created in this study to obtain an automobile VMT change that would be intermediate between optimistic growth and decline. Its artifical nature is apparent when the VMT growth rate is set as exactly zero. It is rationalized that the effect of a reduced, but positive, economic growth rate combined with rising costs of petroleum products will keep up the trip demand but cause a certain amount of modal shift. Therefore the bus VMT growth rate is set one-third higher than the SRI rates in Scenario T_1. This allows for a modest growth in bus trip demand in addition to population growth. Rail transit is assumed to make the same number of trips, rather than to decline as indicated by SRI. The moderation scenario has proven to be very useful.

2.2.3 Decline (Scenario T_3)

In Scenario T_3 the world demand for petroleum fuels exceeds the supply sometime before the end of the century. Some researchers expect this to occur in the 1980's. The government adjusts to this event either by policy measures implemented in advance or by crisis management as shortages materialize.

If the energy shortfall becomes credible to a majority of the people, then the government can take advance actions to soften the impact. The import of oil can be restricted to a certain level, thereby reducing the nation's dependence on other countries. This creates a somewhat artificial shortage in advance of real shortages, but it allows a long-term adjustment. Fuel rationing would be required. Other approaches are to tax crude oil and gasoline or to encourage much

Table 2-2. AVERAGE ANNUAL VMT GROWTH RATES FOR FOUR TRANSPORTATION MODES IN THREE TRANSPORTATION SCENARIOS

Scenario	City	Transportation Mode				
		Automobile	Bus	Rail[a]	Taxi	Heavy Duty Truck
Optimistic Growth (T_1)	New York	0.0071	0.041	(-0.0042)	0.0067	0.0071
	Los Angeles	0.0165[b]	0.033	N/A	0.0043	0.0049
	Chicago	0.0045	0.025	(-0.0016)	0.0039	0.0045
Moderation (T_2)	New York	0	0.055	0	0.0033	0.0033
	Los Angeles	0	0.044	N/A	0.0021	0.0021
	Chicago	0	0.033	0	-0.0020	-0.0020
Automotive Decline (T_3)	New York	-0.0066	0.036	(-0.0024)	-0.0060	-0.0066
	Los Angeles	-0.0076	0.036	N/A	-0.0070	-0.0076
	Chicago	-0.0098	0.031	(-0.00056)	-0.0092	-0.0098

[a] Rail growth rates adapted from SRI are shown in order to present a more complete picture of modal choice, but rail growth rates do not enter into the calculation of emissions from area sources. This study considers only the next 22 years, a time period in which it is considered unlikely that L. A. will complete a rail transit system. Thus the comment "N/A" applies to each scenario.

[b] This figure is derived from projections of the L. A. Air Resources Board.

higher prices. Any effective action of this type will contribute to recessions, thereby reducing the political feasibility of such actions.

Because many people do not believe projections of energy shortages, it is likely that a shortage will be manifested in the form of a crisis. Perhaps one of the major oil producers will suddenly stop its exports to the U.S., due to war or political upheaval. A sudden 5% reduction in the supply is sufficient to cause disruptions in daily living habits. During a crisis prices may rise or else rationing and controls may be implemented. A series of crises would have the long-term effect of reducing the automotive VMT by the end of the century. This is expressed as a negative increase in automobile VMT with a major emphasis on alternative modes of transportation. Automotive VMT data for this scenario are adopted from the SRI scenario "transformation".

It may be noted that even in Scenario T_3, the use of vehicles decreases less than is shown by some of the more pessimistic scenarios used by others. For example, Curry et al. used one alternative scenario for Los Angeles that would reduce automobile usage by 71% over the next 50 years (an average of 1.4% per year).[6]

One of the reasons for moderating some of the more gloomy forecasts is that technology plays a large role in the way society adapts to changing conditions. Alternative automotive fuels are already known which are likely to be developed quickly when they can compete in price with present fuels. For example, liquid and gaseous fuels can be derived from coal-- a plentiful resource. Hydrogen can be developed as a fuel once certain safety problems are overcome. As the price of oil increases these alternatives will become attractive. They could become dominant sources of fuel following a crisis in Scenario T_3 or they could develop more slowly in a planned changeover.

2.3 PROJECTIONS OF MODAL CHOICE

The changes in VMT that were projected for each scenario were based primarily upon two scenarios from the SRI study supplemented by information from other sources (see Table 2-2). The automobile, bus, and rail growth rates for the Optimistic Growth scenario were derived from the "success" scenario of SRI by assuming that vehicle miles are directly proportional to passenger miles. A linear change rate was used to prorate the growth over a 50-year period to each year between 1975 and 2000. SRI data were used because the rationale for these scenarios has already been worked out in detail. However, where data were available from governmental agencies, it was substituted for auto VMT in Scenario 1. The automobile, bus, and rail VMT rates were derived from Curry's "transition" scenario in a like manner.

No data were available in the SRI scenarios on the changes in taxi or heavy duty truck travel. However, the trip demand for both of these types of vehicles can be assumed to vary as a function of economic growth rates. Taxi usage is related to economic activity because it is used by the upper and middle classes to conduct business within the central business district (CBD). With less economic activity the trip demand either drops or converts to other modes. Heavy duty trucks are also related to economic activity because they are the means of transporting goods in the CBD. Projections of taxi VMT changes were made for the New York City CBD and were applied to other cities and other scenarios by observing that taxis receive somewhat more use than automobiles because they are the recipients of passengers under the modal shift changes of Scenarios T_2 and T_3. (The difference between automobile and taxi rates of change were simply applied to the rest of the column.) The rates of change for heavy duty trucks were assumed to be the same as those for automobiles, except for Scenario T_3 where it assumed that a modal shift is accomplished in a positive growth economy. Any modal changes not shown in the table are considered to be either shifts to carpooling or reductions in trip demand.

2.3.1 Los Angeles

One of the early EPA transportation studies was conducted in the metropolitan Los Angeles area by TRW, Inc.[10] Their analysis showed that the dominant use of the automobile in the South Coast Air Basin was the principal source of air pollutants causing violations of the oxidant standard. Despite the need for changes in the transportation system, the improvements that were being planned at that time would result in only minor improvement in air quality. Incentive measures for reducing the automobile miles travelled were judged ineffective for inducing significant changes. Among the measures considered, only gasoline rationing would bring about a sufficient reduction in automobile use to meet air quality standards. The use of personal vehicles could not be restrained in any practical way unless alternative means of transportation were made available. Thus it was projected that none of the proposed controls would allow the region to meet the ambient standards for oxidants by 1977. This has proved to be the case.

The rapid growth of the region to the level of 6 million people occurred during an economic boom period in which the U.S. enjoyed access to the majority of the world's fuel resources. This optimism was reflected in the construction of highways since World War II. For example, in a brief 20-year period, 1950-70, the Los Angeles region increased its freeway mileage by 1390%.[11] In 1967 only 0.1% of all trips were made by taxis. In total, the complete success of then current urban transit projects would have resulted in only a 1.3% reduction in VMT.[10]

Since the 1972 report a number of studies have been conducted to analyze the possible modal split changes that could occur in the Los Angeles area.[12,13,14] For example, the Rand Corporation studied measures that might be effective in reducing the demand for automobile travel.[15] Goeller applied methodology developed in San Diego in a study for the Southern California Association of Governments (SCAG).[14] The SCAG had adopted a goal of 20% VMT reduction to meet air quality requirements in the region.[17] The study looked at the tactics thought to be feasible: bus system improvements, carpooling incentives, and economic disincentives for auto use. It was found that improvement in the bus system could reduce VMT by 10% at best, and this was impractical in the short term. Preferential treatment for carpool vehicles combined with computer matching of riders could possibly achieve 20% reduction. Gas price increases could also reduce VMT by 20%, but the maximum reduction for combined strategies was 30%. Beyond this, some passenger trips would have to be foregone or switched to transit. According to Horowitz, a 30% reduction of VMT would require a modal split of 39:63 (39% by bus), depending on the transit schedule frequencies at peak hours.[13] Without a major crisis, even modest reductions in VMT seemed unlikely.

The Optimistic Growth future (Scenario T_1) for Los Angeles was developed using an automotive VMT projection of the Los Angeles Air Resources Control Board (LAARB).[18] This projection is based on a study of the trend in automobile registrations and driver licenses. An annual growth rate of 1.65% is applied to the 1975 automobile population (3.5 million vehicles) and projected forward. It is assumed that the automotive VMT per year remains constant at 7,897 miles per year per vehicle. LAARB handles the growth of diesel truck mileage in a similar manner. An annual growth rate of 3.75% is applied to the 1975 base year of diesel trucks (22,381 vehicles), assuming that the annual mileage of these trucks will remain constant at 49,318 miles per year. However, it is the heavy-duty truck growth rate that is needed for the definitions of scenarios.

Diesel trucks as defined by LAARB do not necessarily include all the truck weights included by EPA in the definition of "heavy duty trucks" (HDT). Furthermore, a certain amount of diesel VMT growth is attributable to diesel sales penetration into the HDT market. For these reasons, it was consiered more appropriate to use the HDT growth rate derived from SRI data rather than LAARB projections.

In this scenario bus VMT expands to maintain the present level of service in the face of population growth and to serve the handicapped and the elderly. It is affordable because of the booming economy.

Scenario T_2, Moderation, shows a zero rate of VMT growth when averaged over the twenty year period to year 2000. Assuming that the amount of business activity is still increasing, the VMT of heavy duty trucks was assumed to increase, but at a rate one-half as great as that of Scenario T_1. Bus service is projected to increase at a rate one-third greater than Scenario T_1, so that the increase in trip demand due to population growth is accommodated by this mode of transport. This means a significant net change in the transportation habits of the region over a 20-year period.

In Scenario T_3 the economy stagnates, energy sources are sharply curtailed, and the automobile VMT actually declines. The rate of decline was adopted from the SRI "transformation" scenario in which a change of values takes place. As noted earlier, this projection is not as confining as the SRI "disciplined society" scenario.

Since economic activity is curtailed, the growth of heavy duty truck VMT is taken to be negative. On the other hand, bus services expand to accommodate a modal shift, although economic conditions cause total trip demand to drop. The bus VMT growth factor is the same as for Scenario T_2, although expansion takes place for a different reason.

Projections of modal choice in Los Angeles according to these scenarios are given in Appendix A, Tables A-1 to A-3.

2.3.2 New York City

One of the 1972 transportation studies conducted by EPA was conducted in New York City.[19] At that time it was found that the NAAQS for carbon monoxide (CO), oxidants (O_x), and nitrogen oxides (NO_x) were violated, with the highest CO levels observed in the Manhattan downtown and midtown districts. Maximum 8-hour concentrations of 45 ppm CO had been recorded, which is 5 times the 9-ppm standard. In general, a "rollback" of 72%-80% of the 1970 emissions level was required to meet standards.[19] The Federal automotive emission control program was expected to reduce emissions by a substantial amount, but it was expected that transportation controls would be required if the Federal standard were to be met for CO.

The 1972 report examined the necessity for VMT reductions in the Manhattan central district and reviewed the 31 types of control measures that were being considered by the New York City Department of Air Resources. One strategy was the development of a state-administered inspection and maintenance program. Another approach was to reduce VMT in downtown areas by limiting parking, by adopting vehicle-free zones, and by improving traffic flow on other streets. A third approach was the promotion of transit and carpool ridership. Other strategies involved the delivery of goods during non-rush hours and long-range plans affecting land use and transportation. It was observed that some of the necessary measures would have adverse economic effects, if not adverse political effects.

A recent study by the Tri-State Regional Planning Commission (TRPC) reviewed the current air quality plans and transportation plans for the region. While transportation elements of the air quality plan could also be found in the regional transporation plans, TRPC found that "... their study and implementation have not always received the urgent attention recommended in Air Quality Plans."[20] This conclusion was warranted in view of the fact that the 1972 recommendations for transportation controls had not been carried out. The commission staff projected that the present program, relying heavily on Federal emission controls, was not projected to meet air quality standards until 1989 (see Figure 2-8). Lacking the public perception of any crisis, this city (like others in the U.S.), will find it difficult to implement any program that would seriously jeopardize the use of the personal automobile.

It was noted earlier that New York and Los Angeles have vastly different transportation systems stemming from their different development histories. Nevertheless, the changes that can be made in the present systems and in the present modal choices are highly conditioned by common national policies and by the national economy. Therefore the growth rates projected for the future under the three scenarios form similar patterns.

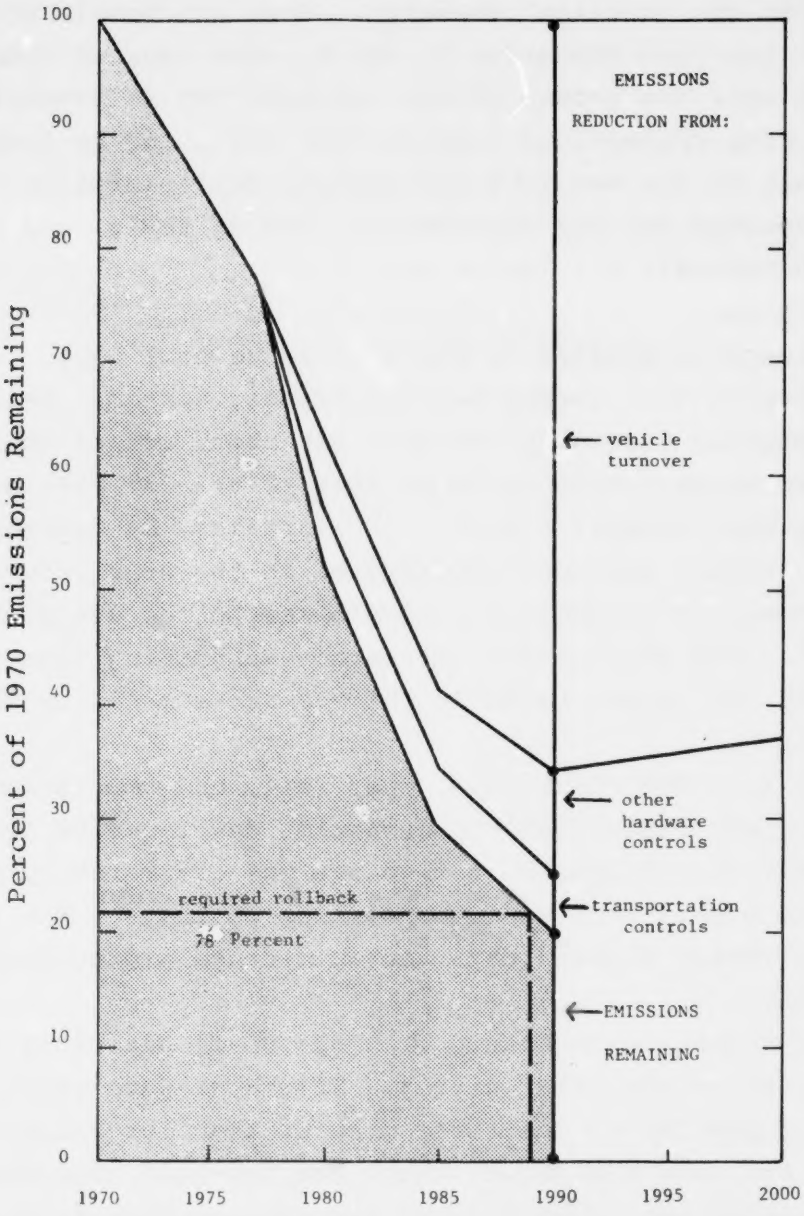

Figure 2-8. Emissions Rollback with Transportation Controls, Carbon Monoxide, Manhattan CBD

Like Los Angeles, the automotive VMT growth rates in New York are positive under the Optimistic Growth Scenario (T_1); are set at zero under the Moderation Scenario (T_3); and are negative under the "decline" scenario. Both automobile and bus VMT growth rates from Scenarios T_1 and T_3 were adopted from SRI propositions. The growth of HDT and taxi VMT in Scenario T_1 was adopted from projections used by TRW, Inc., and by local government in the New York Air Quality Implementation Plan.

Projected VMT for automobiles, HDT's, taxis, and buses are given in Appendix A., Tables A-1 to A-3.

2.3.3 Chicago

Chicago is similar to New York in several ways. It is an older city with an extensive rail transit system. Rail transportation currently accounts for about 18% of intracity passenger miles, which is comparable to the 23% carried by the New York rail transit system. (Los Angeles, by contrast, has no rail transit and none is expected in the near future.) The use of buses in Chicago is also similar to the use of buses in New York. For this reason, it is not surprising that the projected VMT growth rates in Chicago are similar to those of New York.

The data for automobile, bus, rail, and HDT in Scenarios T_1 and T_3 are taken from the scenarios developed by SRI (refer to Table 2-2). Growth in taxi usage was estimated by assuming that taxi growth rate would be similar to that of New York and that the ratios between taxi and auto usage growth rates would be the same.

The Moderation Scenario (T_2) was developed using the same estimations as the other cities. Growth of auto usage is zero, growth of bus VMT is one-third greater than for Scenario T_1, and HDT and taxi VMT growth rates are one-half of Scenario T_1.

The base year data for VMT was approximated from 1970 data provided by the staff of the Chicago Area Transportation Study (CATS). It is their opinion that little change occurred from 1970 to 1976 in modal choice, so this should be a good approximation.[24] Since the base data did not give VMT directly, it had to be approximated. The steps are displayed in Table 2-3 where the number of trips taken by each type of vehicle into or across the CBD is shown in the first column. Some of the truck trips in the source reports were not classified by truck type; but according to the report, it could be assumed that they were of the same type as those that were classified.[25] Therefore, unclassified truck types were proportionately distributed to the three truck categories.

In reviewing the average vehicle trip length, it was found that the trips into or across the CBD exceeded the effective length of the CBD (±5 mi). Therefore, the length of each vehicle trip within the CBD could be taken to be 5 miles. For convenience, the CBD trip lengths were normalized to 1 mile. This could be done because the magnitude of VMT was unimportant; it is the relative VMT of different modes that is used to calculate the relative emissions (see Chapter 5). Thus, passenger trips could be divided by the assumed vehicle occupancy to yield the normalized VMT in the CBD.

Projected VMT for automobiles, HDT's, taxis, and buses are given in Appendix A, Tables A-4 to A-6.

Table 2-3. DERIVATION OF VMT BASE YEAR DATA FOR THE CHICAGO CENTRAL AREA[21,22,24]

Mode	Weekday[a] Passenger Trips x 10^3	Average Trip Length[b]	Assumed Vehicle Occupancy	Normalized VMT
Auto Driver	310	5.1	1	310
Auto Passenger	110	5.0	0	-
Suburban Rail	105	18.5	-	-
Rapid Transit	194	7.9	-	-
Bus	153	3.9	25	6.1
Taxi	74	-	0.5	148
Light Truck	23.7	(5+)	1	23.7
Medium Truck	2.7	(5+)	1	2.7
Heavy Truck	17.5	(5+)	1	17.5

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[a] Chicago Area Transportation Study and Northwestern Indiana Regional Planning Commission, 1970 Travel Characteristics, "Commodities and Commercial Vehicles," Table 34, and "Facility Suppy and Usage", Table 1, 1975.

[b] Reference a, "Trip Length," Table 1. The symbol () means assumed datum.

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3. SCENARIOS OF DIESEL SALES

3.1 DIESEL AUTOMOBILES

The automobile population, because of its large numbers, may continue to contribute a significant part of the total air pollution in coming years. Therefore, it is important to know the distribution of diesel engines in the automobile population for any given year in the future, so that the particulate contribution from these vehicles may be taken into account.

When General Motors made known its intent to use diesel engines, the New York Times reported "by 1985 the new engines may power one car in every four that Detroit produces."[1] The idea that 25% of the new car line will be diesel in 1985 has been repeated in governmental circles over the past year and seems to have achieved the status of conventional wisdom.[2]

Since the diesel represents about 1/2 of a percent of the automotive sales at the present time,[3] rapid diesel introduction should be viewed as a drastic, forced change to meet Federal requirements for fuel economy. However, this particular solution to the problem is proposed by industry. If the health risks of diesel are judged to be tolerable when compared to other alternatives, then the government might accept this change. Simultaneously, if industry can meet particulate emission standards without sacrificing the fuel economy of diesel, then all the major actors will be driving in the same direction. Under this scenario the rapid introduction of the diesel automobile seems very likely. In fact, there would be no reason to stop at 25% in 1985; diesel sales should continue until nearly all automobiles are diesel. A rapid changeover to this type of engine would seem inevitable as all factions push to solve the health and energy problems and as advertising is brought to bear on the public. Conversely, if any one of the major actors finds a significant problem, then it is doubtful that diesel would be used. Some other technology would be selected. Thus, it seems to boil down to either a rapid introduction of diesel, or none. These alternatives can be labeled no diesel introduction (Scenario D_1), or rapid diesel introduction (Scenario D_2).

Let us consider Scenario D_2. The concept of propelling diesel sales from near zero to 25% within a few years implies an accelerated introduction rate. Diesel sales would increase at a logarithmic growth rate (rather than a linear rate) then taper off as the market for diesel comes close to saturation. This phenomenon can be approximated by a cumulative logistic distribution curve--an S-shaped growth curve which is familiar to the engineering sciences. The formula for this curve is as follows:[4]

$$F(x) = \left\{ 1 + \exp^{-}\left(\frac{x - \alpha}{\beta}\right) \right\}^{-1} \tag{1}$$

where

$F(x)$ = the fraction of new automobile sales which are diesel,

x = the projection year of interest, 78, 79, 80,...etc., and

α and β = scaler quantities which determine the shape and slope of the curve.

On this curve we may assume two points: (0.005, 78) and (0.25, 85). From these points we can derive the values of α and β for Scenario D_2 using the step-by-step derivation of formulae for α and β in terms of x and $F(x)$ provided by Johnson[5] (see Appendix B). We find $\alpha = 86.83$ and $\beta = 1.669$, and the diesel introduction curve under Scenario D_2 using Equation 1 above is shown in Figure 3-1.

Note that the fraction of diesel engines in automobile sales is not the same thing as the fraction of diesel in the vehicle population. To estimate the number of diesels in a population for any given year, one must first know the fraction of the vehicle population represented by each model year. The EPA methodology is to use the average frequency distribution for vehicle age found in vehicle registration records. It is

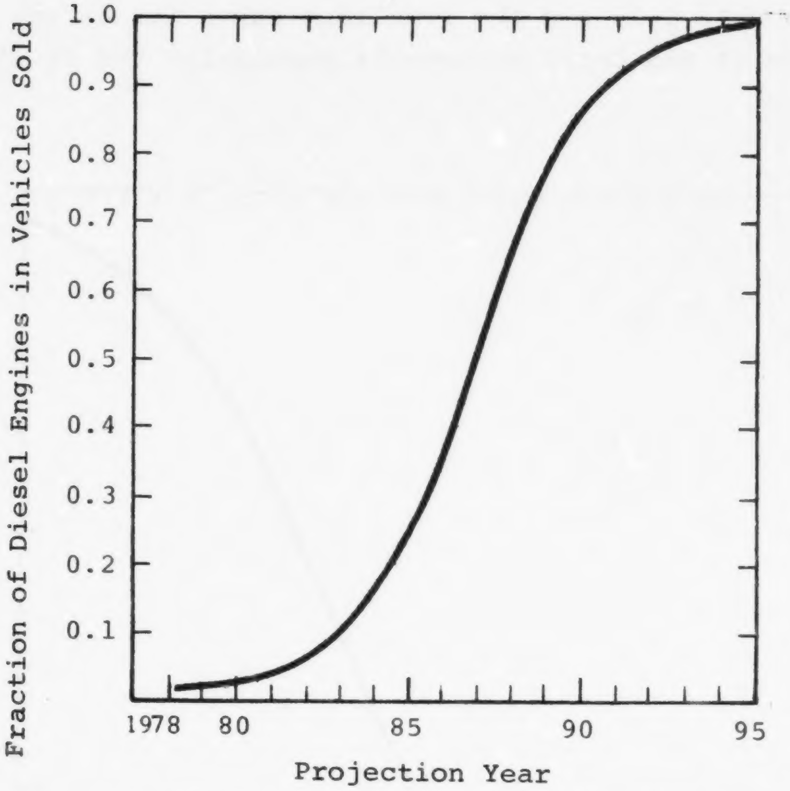

Figure 3-1. Log Growth Phase for Diesel Engine Sales in New Automobiles under Scenario D_2.

then assumed that each year in the future will have this same vehicle age distribution.[6]

Research has also been conducted on the annual mileage accumulation that is typical for various age classes of vehicles. Older vehicles tend to be driven less. The travel fraction is defined as the fraction of total annual VMT attributable to a given age class of vehicles. The travel fraction is obtained by multiplying the annual mileage accumulation for an age class of vehicle by the fraction of the vehicle population in that age class and then by dividing by the sum of such products for all age groups.[7] Under Scenario D_2 the travel fraction attributable to diesel automobiles is obtained by multiplying the travel fraction for each age group by the fraction of vehicles in that age group that were sold as diesel when the vehicles were new, as determined by Equation 1. A table of diesel travel fractions for Scenario D_2 is listed in

Appendix C (Table C-1) and the resulting curve for diesel VMT as a fraction of the total automobile population VMT is shown in Figure 3-2.

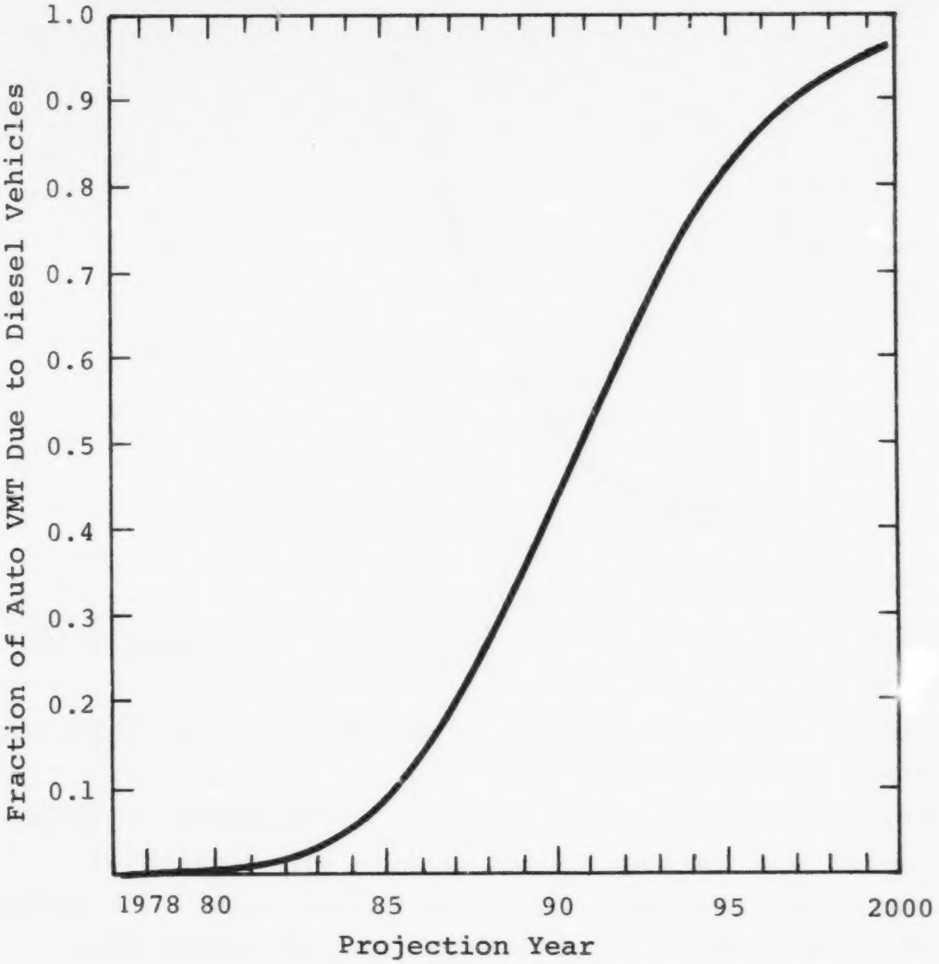

Figure 3-2. Fraction of Total Automobile VMT Attributable to Diesel Vehicles Under Scenario D_2.

3.2 DIESEL TRUCKS

The diesel engine helps to solve some of the problems faced by the trucking industry. For example, the use of diesel engines can help control the fuel costs of trucking operations. The longer lasting diesel engines can also help minimize the capital cost of engine replacement. On the other hand, diesel engines provide less torque and less power per engine kilogram. Overall, the advantages of diesel have caused diesel truck sales to increase rapidly in the last few years.

The fractions of heavy duty truck (HDT) sales that were diesel from 1967 to 1977 are listed in Table 3-1 and are displayed in Figure 3-3. One method of "projecting" the diesel fraction is to obtain a straight line formula that provides the best fit for all the available data. A linear regression analysis performed on the diesel fractions listed in Table 3-1 yields the following equation:

$$F(Y) = 0.0204\ Y - 1.166 \tag{2}$$

where

$F(Y)$ = the fraction of HDT sales that are diesel, and

Y = the projection year of interest.

This equation fits the data with $r^2 = 0.78$, and could be projected forward as shown in Figure 3-3. If this projection were used, 100% diesel sales would be reached in year 2007. However, it can be observed that the diesel sales fractions for 1975 to 1977 form a decidedly different pattern from the pattern of diesel fractions for 1967 to 1974. In fact, the linear rate of increase for the last three years is better described by a different equation:

$$F(Y) = 0.097\ Y - 6.988. \tag{3}$$

If Equation 3 is used to project future diesel sales, we find that 100% dieselization is reached in 1983, only 4 years

Table 3-1. U.S. FACTORY SALES OF HEAVY DUTY TRUCKS FOR DOMESTIC CONSUMPTION[a]

Year	Net HDT Production[b]	Factory Diesel Sales	Diesel Fraction
1967	349,641	70,800	0.202
1968	374,216	83,423	0.223
1969	396,849	101,703	0.256
1970	340,596	91,801	0.270
1971	370,214	101,488	0.274
1972	447,644	129,628	0.290
1973	482,562	152,373	0.316
1974	459,006	144,702	0.315
1975	252,156	72,605	0.288
1976	284,673	107,216	0.377
1977	343,892	165,559	0.481

[a] Source: Automotive News, 1977 Market Data Book Issue, p. 62, and 1978 Market Data Book Issue, p. 49.

[b] Net heavy duty truck (HDT) production equals total U.S. domestic truck production, minus the production of vehicles less than 6,000 lbs GVW, and minus the production of vehicles 6-10,000 lbs GVW. EPA defines HDT's as greater than 8,500 lbs, but the data source did not use this definition. No significant discrepancy is expected, since most HDT's are much heavier than 10,000 lbs.

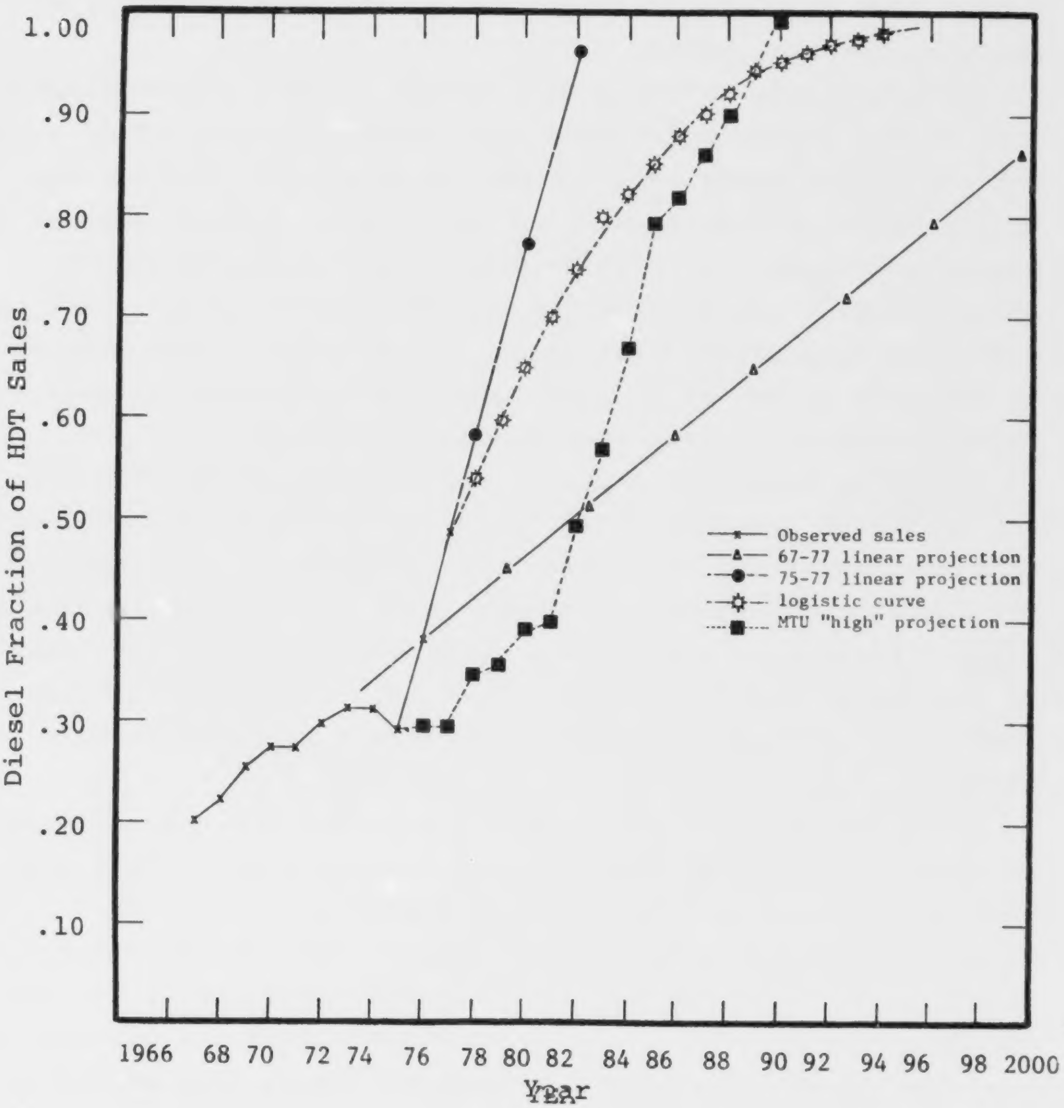

Figure 3-3. Alternate Projections of Diesel Sales in Heavy Duty Trucks.

away. Intuitively, the first linear projection seems "too low" while the second seems "too high". Also, both of these equations reach 100% dieselization--a situation which would seem to be an unreasonably complete domination of one type of engine over another in a field where both have been applied usefully for many years.

A reasonable middle ground can be reached if one assumes that diesel engine sales have been suddenly propelled by a new set of factors since 1973. These factors might include the higher price of fuel as well as the need to control gaseous engine emissions. If this is true, then we should expect diesel sales to enter a period of logarithmic growth, like the growth we have assumed for diesel automobiles in Scenario D_2. In the case of HDT's, we have some hard data which suggest that we have already entered such a stage of growth.

In this study, we chose to assume that diesel sales for HDT's entered a growth phase in 1974 that can be approximated by a cumulative logistic distribution function. The form of the equation was stated in subsection 3.1, and formulae for the α and β parameters are derived in Appendix B. Given the points on the curve (74, 0.315) and (77, 0.481) from Table 3-1, we find $\alpha = 77.33$ and $\beta = 4.281$. The resulting projection is shown in Figure 3-3.

The use of the cumulative logistic distribution formula provides a curve that approaches 1.00 as a limit. This means that we do not expect one type of engine to completely eradicate the other, even if it becomes the predominate choice. It will also be noted that the logistic formula will not fit the data for 1967-73. This is consistent with the assumption that the forces affecting diesel sales during that period were different.

It is interesting to compare this projection with an earlier one based on data that were available in 1974. An economic and emissions model was developed at Michigan Technological University (MTU) to analyze the economic factors that affect diesel sales.[2] Since economic conditions cannot be predicted in advance, the researchers used a wide range of projections. The high projection from that report was used in a prior diesel study[3] and is shown on Figure 3-3. It will be noted that even these high estimates were unable to anticipate the sudden jump in diesel sales that occurred in 1976 and 1977. Nevertheless, the projected rate of increase in sales is very rapid in the early 1980's, and intersects the logistic curve in 1989. The projection we have chosen is somewhat similar to the MTU high projection, but is based on more recent information.

In this study we have chosen to limit the number of HDT scenarios to one in order to keep the number of alternative futures to a manageable level. The trucking industry already uses a significant number of diesel engines (48% in 1974); therefore there will be less change in the diesel fraction for HDT's than for automobiles. Thus the projections of diesel sales for HDT's do not affect the results as much as the projections for automobiles. Furthermore, since the changes in sales are less dramatic, one can expect a more narrow range of possible error in the projection.

Based on the diesel sales scenario, the diesel fraction of VMT by HDT's can be estimated for a given projection year. Following EPA methods, the diesel fraction (f_d) of HDT-VMT is the sum of the travel fractions for each age class (f_{dn})of diesel HDT's, where a travel fraction is defined as the fraction of the total VMT that is attributable to a model year class of vehicle ($f_d = \Sigma f_{dn}$). For automobiles, we multiplied the diesel sales fraction for each model year by the travel fraction for the age class and a given projection year to get the diesel travel fractions. The travel fraction for a model year changes over time and reflects the fact that older vehicles pass out of the vehicle population and that those remaining are driven fewer miles.

This estimating procedure assumes that the diesel and gasoline vehicles have the same travel fractions for the same model years. However, recent research has shown that the travel fractions for heavy duty gasoline (HDG) vehicles are significantly different from the travel fractions for heavy duty diesel (HDD's) of the same model year. (Travel fractions may also differ for automobiles, but research on this has not been done.) For example, 2-year old HDG vehicles will have accumulated 19,000 miles and will have a travel fraction of 0.116. By contrast, 2-year old HDD's will have accumulated 73,600 miles and have a travel fraction of 0.178.[10] In part this reflects the usage patterns of vehicles equipped with diesel engines, and in part it reflects the artificial nature of EPA's definition of "heavy duty" which includes both 8,500-lb and 40,000-lb vehicles. It is the large tractor-trailers which usually contain diesel engines and which are used for long distance hauling.

The differences in HDG and HDD travel fractions necessitate a different methodology for calculating diesel travel fractions. For example, the HDD travel fractions for a model year from Mobile Source Emission Factors are expressed as fractions of the total HDD-VMT rather than fractions of the total HDT-VMT.[6] Yet it is the travel fractions of HDT-VMT that are needed for the definition of this scenario.

The first step in calculating the diesel fraction of HDT-VMT is to find the fraction of the total HDT population that is diesel for each projection year. This is obtained by multiplying the combined gasoline and diesel registration fractions for each model year by the diesel sales fraction for that year according to the HDT diesel sales scenario. Mobile Source Emission Factors did not provide this data explicitly; nevertheless, it is possible to estimate the combined registration fractions from the data provided in the tables of the referenced document. The estimating data are displayed in Table 3-2. The gasoline registration fractions and mileage accumulation rate (columns a and b) are taken directly from Table III-5 in the referenced document, and the diesel fractions and mileage are taken from Table IV-5. The combined fraction is the sum of the other fractions weighted by

Table 3-2. ESTIMATION OF THE COMBINED GASOLINE AND DIESEL HEAVY DUTY TRUCK REGISTRATION FRACTIONS BY VEHICLE AGE CLASS

	Gasoline HDG[a]		Diesel HDD[b]		
	(a)	(b)	(c)	(d)	(e)
Vehicle Age	Fract. of HDG Registration	Annual Mileage Accumulation Rate	Fract. of HDG Registration	Annual Mileage Accumulation Rate	Combined (weighted) Fract. of HDT Registration*
1	0.037	19,000	0.077	73,600	0.069
2	0.070	19,000	0.135	73,600	0.122
3	0.078	17,900	0.134	69,900	0.123
4	0.086	16,500	0.131	63,300	0.122
5	0.075	15,000	0.099	56,600	0.094
6	0.075	13,500	0.090	50,000	0.087
7	0.075	12,000	0.082	45,600	0.081
8	0.068	10,600	0.062	41,200	0.063
9	0.059	9,500	0.045	38,200	0.048
10	0.053	8,600	0.033	36,000	0.037
11	0.044	7,800	0.025	34,600	0.028
12	0.032	7,000	0.015	33,800	0.018
13	0.038	6,300	0.013	33,100	0.017
14	0.036	5,900	0.011	32,400	0.015
15	0.034	5,300	0.010	30,900	0.014
16	0.032	4,900	0.008	28,700	0.012
17	0.030	4,700	0.007	25,700	0.011
18	0.028	4,600	0.006	21,300	0.010
19	0.026	4,400	0.005	18,400	0.009
20	0.024	4,200	0.004	15,400	0.008
Totals:	1.000		0.992		e_n = 0.998

[a] HDG = heavy duty gasoline truck

[b] HDD = heavy duty diesel truck

[c] (e) = (ab + cd) ÷ (b + d)

the mileage accumulation rate, as follows:

$$e_n = (a_n b_n + c_n d_n) \div (b_n + d_n) \qquad (4)$$

where

e_n = the combined gas and diesel HDT registration fractions for vehicle age class n,

a_n = the fraction of total gas HDT's of age class n,

b_n = the annual mileage accumulation rate for age class n for gas HDT's,

c_n = the fraction of total diesel HDT's of age class n, and

d_n = the annual mileage accumulation rate for age class n for diesel HDT's.

In other words, this estimation takes into account the difference in mileage accumulation between diesel and gas HDT's, and weighs the individual fractions accordingly. The sum of all e_n is in error by only 1.2%.

The combined gas and diesel HDT registration fractions are then used to calculate the diesel fractions of HDT's on the road, as shown in Appendix C (Table C-2). Each entry in the table represents the combined registration for each age group multiplied by the diesel sales fraction that was applicable to that age group when the vehicles were new. The fractions at the top of the column apply to age class 1 for that projection year, apply to age class 2 in the following year, and so on in a stepwise fashion. The total fraction for each projection year is charted in Figure 3-4. According to this projection, gasoline engines remain in the HDT population through the end of the century.

The first step in estimating the diesel fractions of HDT-VMT was to calculate the diesel fraction of HDT's on the road according to the HDT sales scenario. The second step is somewhat more tedious. Tables C-3-78 through 3-4-2000 (Appendix C) show the calculation steps for each projection year.

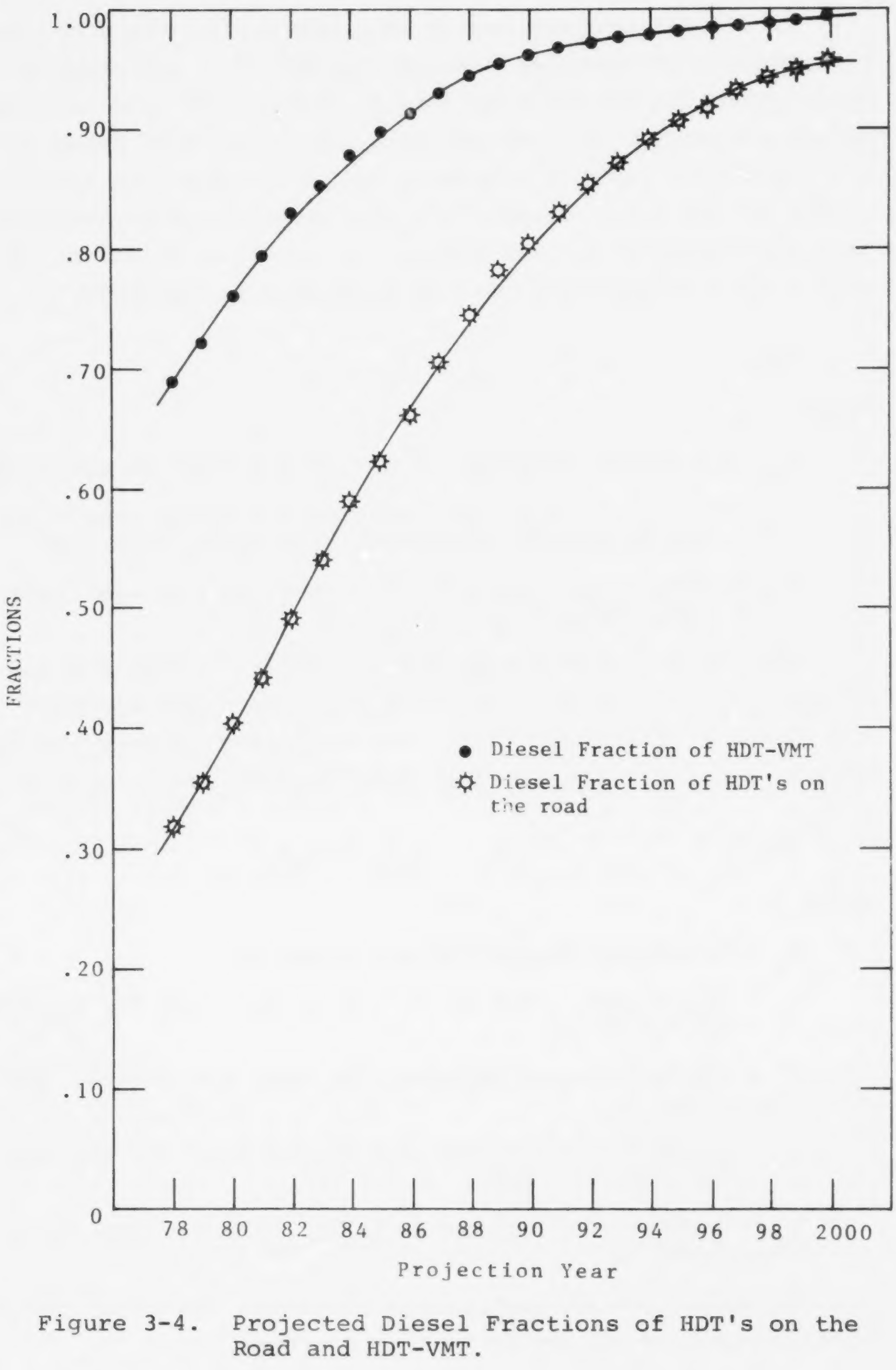

Figure 3-4. Projected Diesel Fractions of HDT's on the Road and HDT-VMT.

In all EPA projections it is assumed that the model year distribution of vehicles remains constant for any projection year. Thus the diesel fractions of HDT on the road (column "a" on the estimation tables) are taken directly from Table 3-3 for the projection year of interest, while the gasoline fractions of HDT on the road (column "c") are obtained by subtraction from the combined gas and diesel registration fractions (Table 3-2). This relationship can be expressed as follows:

$$f_{gn} = f_n - f_{dn} \tag{5}$$

where

f_{gn} = gasoline fraction of HDT on the road of age class n,

f_n = total registration fraction for model year n for the HDT projection scenario (from Table 3-2), and

f_{dn} = diesel fraction of HDT on the road of age class n from Table 3-3.

The annual mileage accumulation rates (columns b and d in Tables C-3-XX) were obtained from the referenced document[6] and are the same as in Table 3-2. The weighting factors for each vehicle age class are obtained from the following formula:

$$w_n = a_n b_n + c_n d_n \tag{6}$$

where

w_n = weighting factor for age class n,

a_n = the diesel fraction of HDT on the road for vehicle age class n,

b_n = diesel mileage accumulation rate for vehicle age class n,

c_n = gasoline fraction of HDT on the road for vehicle age class n, and

d_n = gasoline mileage accumulation rate for vehicle age class n.

Following the EPA definition of travel fraction, the diesel travel fractions may be defined as follows:

$$(7)\quad \text{Diesel Travel Fraction} = T_{dn} = \frac{a_n b_n}{{}_{n=1}^{20} w_n} = a_n b_n \left[\sum_{n=1}^{20} a_n b_n + c_n d_n \right]^{-1}$$

Thus the diesel travel fractions in the estimation tables (Appendix C) provide statements of the fraction of HDT-VMT attributable to diesel for each vehicle age class and for each projection year of interest.

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9. Automotive News, *1978 Market Data Book Issue*, p. 49.

10. Ref. 6, Tables III-5, III-5a, IV-5, IV-5a.

4. EMISSION FACTORS

4.1 EMISSION FACTORS IN SCENARIO E_1

The present methods of estimating the amount of particulate emissions from vehicles are relatively unsophisticated. Most of the emissions research in recent years has been directed towards gaseous pollutants, and the estimating procedures for gases are more highly developed. The particulate emission factors for automobiles, whether gasoline or diesel, are based almost entirely upon a factor assigned to a model year class of vehicles, and they have not been corrected for vehicle deterioration, maintenance conditions, types of fuels, or types of operating cycles.[1,2] The emission factors that were available from a prior study of diesel particulates were labeled E_1 and treated as a scenario alternative.[3]

In past years, the particulates from gasoline automobiles were composed predominately of lead compounds, usually about two-thirds PbClBr and about one-third $NH_4Cl \cdot PbClBr$. Prior to 1975, automobiles were the noncatalyst type and more than 95% of the gasoline consumed contained lead to boost the octane rating of the fuel. Hoggan[4] found that the lead concentration in the atmosphere of Los Angeles had declined from 1970 to 1976 due to a reduction in the amount of lead in both regular and premium gasolines. The average lead concentration in the atmosphere could be calculated from the amount of leaded gasoline consumed. Nevertheless, the methodology used in this study utilizes the EPA emission rates for vehicles so that particulate emissions can be estimated for projection years when lead is not the primary particulate of concern. In any case, comparable results are expected, since the amount of unleaded gasoline consumed is related to the number of catalytic vehicles in use.

The current particulate emission factor used for pre-1975 automobiles is 0.25g/VMT, based upon the use of leaded fuel. The pre-1975 emission factor for unleaded fuel use is 0.002g/VMT, but the fraction of pre-1975 vehicles using unleaded fuel is considered insignificant for the purpose of this calculation.[3] For production model years 1975 and thereafter, catalysts are the predominant method for meeting the EPA emission control requirements. It is assumed that 70% of the automobile population use catalysts with an emission factor of 0.006g/VMT and that 30 percent use catalysts with excess air which have an emissions factor of 0.015g/VMT. (Catalyst vehicle emissions are due to sulfates rather than lead.) Based on this premise, the gasoline vehicle model classes manufactured in 1975 and beyond have been assigned a weighted emission factor of 0.0087 g/VMT (calculated as 0.7(.006) + 0.3(.015). Obviously this value is not based on a detailed analysis of the distribution of catalytic equipment in production vehicles, but it is a degree of accuracy commensurate with the available emission factors.

In any given projection year the combined emissions from automobiles will depend upon the age class distribution and the particulate emissions factor assigned to each age class of vehicles. A table of travel-weighted particulate emission factors has been prepared for Scenario D_1 and is presented in Appendix D, Table D-1.

In Scenario D_2, a certain fraction of each automobile age class is diesel, and an emission factor of 0.5g/VMT is assigned to this subclass. For each projection year, the travel-weighted particulate emissions can be calculated using the following convenient equation:

$$(1) \qquad E_{tn} = e_{gn}(t_n - t_{dn}) + 0.5t_{dn}$$

where

E_{tn} = the travel-weighted particulate emissions factor for vehicle age class n under Scenario D_2,

e_{gn} = the particulate emissions factor for gasoline vehicles applicable to vehicle age class n,

t_n = the travel fraction for vehicle age class n (from EPA-400/9-78-006),

t_{dn} = the travel fraction for diesel vehicles under Scenario D_2 for age class n (from Table A-1), and

0.5 = the diesel particulate emission factor applicable to all diesel automobiles under Scenario E_1.

The emission factors for heavy duty trucks can be handled in a manner similar to that used for automobiles. The emission factors for pre-1975 HDT's is 0.90g/VMT based upon the use of leaded fuel. The pre-1975 HDT emission factor for unleaded fuel is 0.007g/VMT, but the fraction of pre-1975 vehicles presently using unleaded fuel is considered insignificant for the purpose of this calculation. Following the procedure of the pilot study,[3] 1977 truck and bus production data were reviewed in order to roughly estimate the technological split in post-1975 HDT's. About 60% would use standard catalysts, and about 40% would use catalysts with excess air. Standard catalyst HDT engines have a particulate emission factor of 0.02g/VMT, while HDT catalysts with excess air have an emission factor of 0.05g/VMT. Thus the sales-weighted emission factor would be estimated as 0.032g/VMT (0.6 x 0.02) + (0.4 x 0.05) = 0.032 . Such a factor is approximately correct if the present technological split is assumed to remain the same in the future.

Using the pre-1975 and the post-1975 emissions factors, weighted emission factors can be calculated for gasoline HDT's for each projection year (Appendix D, Table D-3). These factors take into account only the above emission factors and the travel fraction represented by each model year according to Mobile Source Emission Factors.[4] The travel fraction applicable to a particular model in a given projection year is simply multiplied by the emission rate to yield the entries in the columns on Table D-3. Thus, the sum of each column represents the weighted gasoline HDT emission factor for that projection year.

The emissions from HDT's for a given projection year is the sum of the emissions from HDT's and HDG's. The HDD emissions are found by multiplying the applicable diesel travel fraction by the diesel emission factor (0.9g/VMT) used for all years. The calculation of total HDT emissions is shown in Table D-4.

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5. Motor Vehicle Manufacturers Association, World Motor Vehicle Data, 1978 ed., published by MVMA.

5. METHOD OF ANALYSIS

The increased use of diesel engines in the future may involve increased emissions of particulate matter. Increased diesel usage could arise because of a shift in the choice of transportation systems or because of the introduction of diesel engines into the automobile population. The actual amount of emissions will also depend on the amount of control that can be built into diesel engines, as expressed through emission factors. If large cities were to change their transportation systems in order to meet air quality standards for gaseous emissions or to reduce the energy costs of transporting people, would they face new problems from increased levels of TSP or polycyclic organic material (POM) associated with diesel engines? The question is especially poignant for present nonattainment areas for TSP and for areas marginally in compliance with ambient air quality standards.

This question can be posed in an analytic framework:

1. Assume that the rate of emissions (Q) for a given pollutant is known for a given city, and

2. Assume that the portion of these emissions that actually affects a given ambient air quality monitoring site (Q_a) is known, and

3. Assume that the portion of Q_a that is emitted from the transportation system (Q_{at}) is known, and

4. Assume that the relationship between Q_a (which includes Q_{at}) and the resulting measured air quality level (χ) at the monitoring site is known. (This is the relationship resulting from local meteorological conditions, terrain, and the distances between emission sources and the monitor.)

Then, one can observe the air quality levels resulting from emissions for a given base period, calculate the change in Q_a caused by emissions from a different set of circumstances as expressed in alternative future scenarios (Q_{at2}), and calculate the new air quality level (χ_2) expected from this change. Another way of expressing the problem is to ask: If all factors in the base period are kept constant except the transportation system emissions, what new levels of ambient air quality can be expected?

5.1 RELATING EMISSIONS TO AMBIENT AIR QUALITY

The method that is traditionally used for most types of air quality assessments is atmospheric dispersion modeling. Such a method is aimed at defining the mathematical relationship between pollutant emissions and air quality under a wide variety of meteorological conditions, in fulfillment of assumption 4 above. For example, modeling is recommended for the analysis of the effects of a new point source of emissions in an air quality maintenance area.[2] It may also be used to assess new sources which are subject to review under PSD (prevention of significant deterioration) requirements. Perhaps the best application of area-wide models is in the development of a regional air pollution control plan, such as the plan developed for the control of suspended particulates in the Phoenix, Arizona area[3] or for the analysis of particulates in Federal Region VIII.[4] The EPA makes available to the professional public a series of computerized air dispersion models on magnetic tape which may be ordered through the National Technical Information Service.[5]

For a number of years, one of the basic modeling tools has been the Air Quality Display Model (AQDM). It was the first model promoted by the EPA for air quality planning.[6] It is applied on a region-wide scale, using grid squares for regional subdivisions. The amounts of emissions are estimated from an emissions inventory by using emission factors to estimate industrial point source emission rates. The dispersion of pollutants is estimated by a Gaussian distribution formula,[7] which is used to allocate a portion of each emitter that is effective at given receptor sites, usually air quality monitoring sites or the centers of grid squares. Area sources are handled by pragmatically assigning the estimated emissions to the center of a grid square and otherwise treating them like point sources.

The principles of estimation by means of Gaussian plume formulae have been set forth by Turner.[8] Pasquill stability classes which underlie these estimates were originally developed from measurements in open rural areas, such as grasslands, rather than in urban conditions with buildings, street canyons, or other terrain.[8,9] In general, the representativeness of data from models can be adversely affected by complex terrain, by the presence of large bodies of water, and by rural assumptions within city conditions. Updated versions of the AQDM have ameliorated these problems.[10] A more recent regional model called RAM is available, but its validity is still being tested.[11] Regional modeling seems most appropriate for interior cities of moderate size where the underlying assumptions are better met.

In a recent pilot study[1] of the effects of future diesel fuel use on particulates, the AQDM was chosen as a vehicle for analysis, and the test city chosen was Kansas City, Mo. As an interior city of moderate size, it was a good candidate for this approach. Even more important, diffusion modeling data were already available and easily accessible to the investigator, who had experience in its application in this particular area.

By contrast, the present study focuses upon three very large urban areas: New York, Los Angeles, and Chicago--each of which is located near a major water body. Regional modeling may or may not be rigorously valid in these areas. More important, it was clearly unfeasible to acquire dispersion modeling data for such areas, to validate the models, and to apply them to the present short-term study. It was desirable to establish a method for addressing the questions posed in the study without the involvement of a complex modeling procedure.

One of the alternate methods for analyzing air quality problems is the "normalizing" of air quality data for a standard set of meteorological conditions. This is most often applied in the analysis of air quality trends. For example, suppose air quality data from a monitoring site generally downwind from a point source show an improvement in the annual average for a given pollutant over a 4-year period. Is this improvement due to a reduction in source emissions or due to better meteorological conditions in the later years? To answer this question, one could follow the procedures recommended by Zeldin and Meisel[12] as follows:

> 1. Find the meteorological factors affecting a given monitoring site by means of scatter diagrams and analysis of variance. Use these factors to establish meteorological classes--each class having a different average concentration associated with it.
>
> 2. Using meteorological records over a 5-year period, establish an average or "standard" meteorological year, with a typical frequency distribution for each of the classes over a year.
>
> 3. Annual measures of pollutant levels are adjusted to "what they would be if each year had the same meteorogy". That is, since atypical meteorology would be reflected in different frequency distributions for the meteorological classes, the observed average for a year within each class is weighted by that proportion of the year which it would "normally" represent.

In the above example, after each year's monitoring data is normalized for meteorology, the remaining variation can be attributed to source emissions.

In this diesel study, one can normalize meteorology in a similar manner, and the remaining variation can be attributed to variations in emissions (Q). If at the same time, one keeps point source emissions the same--that is, one assumes no yearly fluctuations in point source emissions, then we must deal only with the effects of a changing transportation system on the air quality levels at selected monitoring sites. This is precisely what we wish to analyze.

In a well-known equation of urban air pollution potential, Holzworth[18] used the following expression:

$$(1) \qquad \frac{\bar{\chi}}{Q} = 3.613H^{0.130} + \frac{S}{2HU} - \frac{0.088UH^{1.260}}{S}$$

where

$\bar{\chi}$ = average ambient air concentration,
Q = average emission rate,
H = mixing height,
S = distance across a city, and
U = wind speed.

This formula shows that air pollution potential can be expressed as a function of mixing height, wind speed, and city size. Disregarding for the moment whether these are the appropriate meteorological factors or whether the above equation is the appropriate formula, consider the following: if meteorology is normalized, then it may be considered a constant for the purposes of this analysis. In other words, for a standard meteorological year M:

$$\frac{\bar{\chi}}{Q} = k \tag{2}$$

Thus, if a procedure for normalizing meteorological data is adopted, it becomes possible to estimate changes in $\bar{\chi}$ directly from changes in Q. This analytic relationship was suggested by Peterson[13] among others. In form it is a rollback equation, as previously described by de Nevers and Morris.[14]

Since this seemed to be a fruitful approach, three methods of normalizing data were considered, with emphasis upon appropriateness of assumptions and on the time and expense of conducting the analysis:

1. Meteorological Classification. The procedures suggested by Zeldin and Meisel[12] were preceived as valid for this project. However, because of the number of sites (16) and the number of meteorological factors (6) to be analyzed in each city, and becaise pf the several observation posts in each city with combinations of factors at each post, it appeared that a significant expense could be committed to this step alone. Furthermore, the retrieval of this quantity of meteorological data and the structuring of data into computerized files were significant. Thus, some alternative method was desired.

2. Average Year Analysis. Johnson[15] proposed that a simplification of the standard year would allow a considerable saving in analytical expense. For example, if monitoring data were available for a 3-year period,

all the air quality data from that period could be averaged to obtain a standard meteorological year. Each air quality measurement would represent a certain combination of emissions and meteorological conditions, to be averaged over the base period. If emissions could be assumed to be constant over the base period, then the variation in measured levels would be due to meteorological variations. In other words, meteorological classes could be established strictly on the basis of the levels of air pollution. This also means accepting a 3-year normalization period rather than 5 years.

3. Single Year Analysis. This procedure would be essentially the same as #2, except that only one year of monitoring data would be employed rather than three. This would be the simplest and least expensive method of proceeding. However, it was ruled out for three reasons. First, any one year that is selected could turn out to represent a meteorological anomaly. Second, the problem of a point source affecting a monitoring site is exacerbated if only one year is taken into account. Third, a number of good sites had data missing for certain months; therefore, data from only one year alone was insufficiently representative of the full range of meteorological conditions.

The average year analysis (#2 above) was chosen for this study. Non-vehicle emissions were assumed to be constant, so that the effect of vehicle emissions could be isolated and analyzed. Therefore, the "projections" used throughout this report cannot be considered "predictions" because point sources are not taken into account. Rather, the projections should be considered as simply a tool for analyzing the effects of a given set of scenario conditions and their relative impacts.

Some of the anomalies of this procedure should be noted.

An examination of the analytic equation (Equation 2) shows that $\ln \bar{\chi} = \ln k + \ln Q$. Therefore incremental changes in $\bar{\chi}$ may be expressed as follows:

$$(3) \qquad \frac{d\bar{\chi}}{\bar{\chi}} = (0) + \frac{dQ}{Q}$$

When a simple ratio formula such as Equation 2 is established, an analysis of the changes in the numerator is completely insensitive to the magnitude of the denominator. In other words, a given percentage change in the denominator (regardless of its magnitude) will yield the same percentage change in the numerator. Thus, many of the parameters in this study can be expressed as fractional parts of Q, rather than as real units. The magnitude of these parameters is irrelevant; only the relationship between parts is important.

It may be noted that the formula used was essentially the ATDL air dispersion model[16] in the form:

$$(4) \qquad \bar{\chi} = CQ/U$$

where

$\bar{\chi}$ = ground level air concentration,
C = dimensionless parameter,
Q = area source emissions, and
U = wind speed.

The only change is that under our meteorological normalization procedure, U becomes a constant, and thus C/U = K, and the above may be expressed as Equation 2. This model is considered appropriate for the estimation of atmospheric pollutants from area-wide sources. It is available on tape as a part of the User's Network for Applied Modeling of Air Pollution (UNAMAP).[5]

5.2 ALLOCATING EMISSIONS TO RECEPTOR SITES

The next step is to ascertain a method for determining the factor (Q) representing the total emissions affecting a receptor site. This procedure is usually carried out by an allocation of each emission by means of dispersion formulae and a statistical treatment. The analytic formulae (Equation 2) is insensitive to the magnitude of Q_a, but it is very sensitive to the proportion of Q_a that is derived from transportation elements (Q_{at}). It is very important to know the percentage contribution of vehicle emissions to the overall emissions.

In the pilot study on diesel effects in Kansas City, it was found that increased diesel use would increase the annual average TSP level by less than $2 \mu g/m^3$. However, transportation emissions represented only 2.9% of the Kansas City[1] totals, while they represented 37-66% in the cities of this study. The fraction of total emissions that are from the transportation sector appears to be one of the key factors in the future year TSP estimates.

Normally, estimating procedures are used to allocate vehicle emissions to receptors. In recent years, however, it has been increasingly feasible to replace estimates with actual measurements. Trace element studies have been carried out in two of the cities in this study which provide an improved level of accuracy in calculating the contributions of various sources to the ambient air quality. Using lead as a tracer for those years in which leaded gasoline was dominant, researchers have measured the automobile component of effective emissions, and the results were used in this study.

Kleinman[19] conducted an extensive study of trace elements and TSP at three sites in New York City. Routine sampling and analysis were conducted from 1969 to 1975. From this data base, a mathematical model was developed by him to explain levels in ambient TSP as a function of the levels of 13 elements: Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, V, and Zn. Using various techniques, the concentration of these elements in particulate matter give an indication of the source of the particles. Some of the elements may be emitted from different sources, but the source of airborne lead is unequivocably motor vehicles. According to Daisey et al.,[20] if the ratio of lead to particulate matter is known for automobile exhaust and if all the lead in a given aerosol originates from automobile exhaust, then the aerosol concentration of lead can be used to estimate the contribution of this source to TSP. One of the results of Kleinman's study was that the automobile contributed about 20-25% of the TSP in New York City in 1975, or about $12 \mu g/m^3$ annual average at the sites tested. Table 5-1 shows the variation in source contributions by year from this study.

The automobile's contribution to TSP in New York City (Table 5-1) is less than was shown on the NEDS emissions inventory data. However, the average lead concentration ($12 \mu g/m^3$) is much higher than the levels found in comparable studies, especially in smaller cities.

Table 5-1. CONTRIBUTIONS OF MAJOR AIR POLLUTION SOURCES TO SUSPENDED PARTICULATE CONCENTRATIONS[a]
(Percent of Measured TSP)

SOURCE	1969	1972	1973	1974	1975
Space Heating and Power Generation	22	8	10	10	8
Automobiles	8	18	23	21	21
Incineration	21	4	4	4	4
Soil-Derived Particles and Possibly Coal Fly Ash[a]	28	14	15	14	16
Sulfate related and Sea Salt	12	20	22	23	29
Subtotals:	91	64	74	72	78
Industrial and Unidentfied	19	31	32	26	49
Total:	110%	95%	107%	98%	128%

[a] for 1969 data.

Source: Kleinman, Michael T., The Apportionment of Sources of Airborne Particulate Matter, New York University, New York, June 1977, p. 138.

For example, Solomon et al.[21] found that the ambient levels of lead at 19 sites in Champaign-Urbana, Illinois, ranged from 0.2 to 2.8$\mu g/m^3$, with the highest levels found in the central business district. This result is consistent with the findings in a prior report by PEDCo Environmental, Inc., wherein the automobile contribution to TSP problems in Kansas City was found to be a very small portion of the total (2.9%).[22] Apparently there is a substantial difference between the severity of motor vehicle particulate effects in small cities and the effects in large cities.

Hoggan et al.[23] have studied the amount of lead in the atmosphere in Los Angeles. This city experienced a 50% decline in the amount of lead in the atmosphere between 1970 and 1976. This reduction was almost wholly attributable to the decline in the use of leaded gasoline combined with a decline in the amount of lead in leaded gasoline. Even at the worst monitoring site in the study (station 76), the 1971 mean annual lead concentration was only 8$\mu g/m^3$, which is less than the 12$\mu g/m^3$ found by Kleinman in New York. A comparable figure for the Los Angeles CBD in 1975 would be 3$\mu g/m^3$, or about one-fourth the level found in New York.

Other studies conducted in the Los Angeles area tended to confirm that the automotive contribution to TSP effective at monitoring sites is less than Kleinman's findings in New York City. For example, Hidy and Friedlander[24] estimated the auto exhaust contribution to the urban TSP aerosol in Los Angeles as 13%. Since this figure is consistent with findings of others, it has been used in this study.

The reason for the lower automotive TSP contribution in Los Angeles (compared to New York) is not known, but several possibilities are apparent. The first is the tighter controls on automobiles exercised by the California State Air Resources Board, including regulations on the lead content in gasoline. This influence would have its greatest effect in the early 1970's. The second reason is the fact that TSP effects on monitoring sites can be highly localized. Central business districts tend to have elevated TSP levels because of more intense use of local streets and because the canyon effects of large buildings tend to reduce dispersion. In this regard, one would expect greater local effects in Manhattan Island than anywhere else.

In the course of work, no trace element studies were found that would help determine the proportion of TSP attributable to automobiles in Chicago. However, the land use and transportation patterns in the central business district are more similar to New York than they are to Los Angeles, and the local effects on monitoring sites should be similar. On the other hand, Chicago has a significant industrial TSP contribution which would suggest that the proportion due to vehicles would be less. The datum 17%, applied as an estimator for the city of Chicago, represents a mean between the other two available figures.

5.3 MONITORING SITE DATA

The selection of ambient air quality monitoring sites and the obtaining of monitoring data of adequate quantity and quality represented a significant problem in this project.

First, the monitoring sites in these three cities have been established for objectives different from the objectives of this study. Second, the use of the national system for the Storage and Retrieval of Aerometric Data (SAROAD) entailed the evaluation of data of questionable quality.

The aim of this study is the evaluation of vehicular emissions under various conditions; therefore it was desirable to select monitoring sites in the central business districts (CBD's) of large cities where one would expect the worst problems. The CBD represents the destination point for a great deal of morning and afternoon commuting by automobile, bus, and rail. The CBD contains the end loop of most bus routes and a transfer point for others. Goods are transported into the CBD by heavy duty trucks, and much business and social interchange takes place using taxi transportation.

Ideally, all monitoring sites used in this type of study should be labeled "center-city commercial" according to the

SAROAD language codes. Each site should be located close to ground level or "breathing zone" so as to represent the exposure of people on the street. EPA has recommended that ambient TSP monitors be located at a height of 2-15 meters and 5-25 meters from any roadway. Monitoring sites too close to a street would sample the plume from street traffic and would not represent the 24-hour exposure of the populace.[29] Each site should be monitored on a continuous basis, or at least frequent enough so that a valid annual geometric mean can be calculated for comparison with the National Ambient Air Quality Standards. There should be a sufficient number of monitoring sites so that the data will reflect the widely varying local conditions affecting TSP levels. The selected sites did not entirely meet the above criteria, but they represented the best choices available from the SAROAD data network.

The five New York sites selected were all located in Manhattan Island in order to represent the central city as much as possible. These were the only active sites in Manhattan which had data throughout the base period (see Table 5-2).[25] It is expected that these sites may be considered "center-city commercial," although the SAROAD system did not list this information for 3 of the 5 sites. All of the sites are near large buildings, although two sites have large open spaces on one side. (Pier 42 monitoring site is next to the Hudson River and the Central Park Arsenal site is next to Cental Park.) The air sampling at these sites is conducted far above street level. For the 121st Street site air was sampled at 75 ft in 1975 and at 24 ft in 1976. The heights of other sites are not correctly listed in SAROAD, but are known to be elevated above the street.[26]

One of the problems encountered in New York was that the SAROAD system did not contain all the data that had been collected at the sites by the local agency. By comparing the number of observations in the SAROAD report with the data reports from local government,[26,27] it was ascertained that there were whole months with data missing. Of the five sites selected, four of them had 3 months of data missing during 1976

TABLE 5-2. CHARACTERISTICS OF MONITORING SITES USED IN ANALYSES

City/County	Site Address	Station Type	SAROAD Code	Elevation Above Ground	Years Of Data	Months Missing	Number Of Observations
1. New York, New York	Steinman Hall W. 141 St. and Convent Ave.		334680057F01		1975	3	40
					1976	0	42
					1977	0	49
2. New York, New York	170 E. 121 St.	Center City - Commercial	334680014P01	75 Feet	1975	0	25
					1976	3	21
			334680014F01	24 Feet	1976	10	5
					1977	0	60
			334680014H01		1975	0	106
					1976	3	62
					1977	3	64
3. New York, New York	Central Park Arsenal, 5th Ave. and 64th St.	Central City - Commercial	334680005H01		1975	0	120
					1976	3	78
					1977	3	100
4. New York, New York	240 2nd Ave.		334680010H01		1975	0	90
					1976	3	75
					1977	3	69
5. New York, New York	Pier 42, Morton St. and Hudson River		334680010H01		1975	2	62
					1976	3	53
					1977	3	40
6. Chicago, Cook Co.	3500 E. 114 St.	Central City - Industrial	141220022H01	31 Feet	1975	0	98
					1976	0	115
					1977	0	113
7. Chicago, Cook Co.	1947 W. Polk	Suburban - Commercial	141220033F01	15 Feet	1975	0	59
					1976	0	60
					1977	1	53

TABLE 5-2. (CONTINUED)

City/County	Site Address	Station Type	SAROAD Code	Elevation Above Ground	Years Of Data	Months Missing	Number Of Observations
8. Chicago, Cook Co.	9800 South Torrence Ave.	Center City - Industrial	141220030H01	16 Feet	1975	1	83
					1976	0	114
					1977	0	109
9. Chicago, Cook Co.	538 S.Clark St.	Center City - Commercial	141220005H01	133 Feet	1975	0	101
					1976	0	116
					1977	0	111
10. Chicago, Cook Co.	4015 North Ashland Ave.	Center City - Commercial	141220004H01	64 Feet	1975	0	88
					1976	0	118
					1977	0	113
11. Torrance, Los Angeles	2300 Carson St.	Center City - Residential	058260001P01	4 Feet	1975	9	8
			058260001F01	4 Feet	1975	3	21
					1976	0	61
					1977	1	54
12. Los Angeles, Los Angeles	434 S. San Pedro St.	Center City - Commercial	054180001I01	72 Feet	1975	0	61
					1976	0	60
					1977	3	46
			054180001P01	100 Feet	1975	10	5
			054180001F01	100 Feet	1975	3	21
					1976	0	57
					1977	0	60
13. Long Beach, Los Angeles	2655 Pine Ave.	Center City - Commercial	054100001F01	25 Feet	1975	3	19
					1976	0	55
					1977	1	52
			054100001A01	25 Feet	1977	11	4
			054100001P01	25 Feet	1975	9	8

TABLE 5-2. (CONTINUED)

City/County	Site Address	Station Type	SAROAD Code	Elevation Above Ground	Years Of Data	Months Missing	Number Of Observations
14. Pasadena, Los Angeles	1196 East Walnut St.	Center City - Commercial	055760004I01	18 Feet	1975	0	61
					1976	0	61
					1977	3	45
15. Pasadena, Los Angeles	Keck Laboratories, California Institute of Technology	Center City - Residential	055760002P01	60 Feet	1975	9	7
			055760002F01	60 Feet	1975	3	21
					1976	0	59
					1977	0	59
16. Lennox, Los Angeles	11408 La Cienega Blvd.	Center City - Commercial	053900000I01	20 Feet	1975	0	61
					1976	0	61
					1977	3	44

Source: EPA National Aerometric Data Bank, "Raw Data Listing-24 Hour", computer printout, run date December 14, 1978.

and 1977. No special pattern was observed in these "gaps", but insufficient data was available during these years to calculate a valid annual geometric mean. The problem was ameliorated for the purpose of this study by using three years of data (1975-77) to represent the base year 1976. This allowed the data gaps for any given month to be represented by data from that month in other years. Thus the standard normalized meteorological year is slightly different for each monitoring site; but this is unimportant as long as the definition of the normalized base year is understood.

In Chicago, there were no special data problems in the five monitoring sites that were selected. However, not all of the sites are located in the commercial downtown district. Two are located in an industrial area near the CBD, one is located in a nearby residential district, and the other two are in the CBD. The sampling height during 1975-77 ranged from 15 to 133 ft. All selected sites had good data records and were located within Cook County, the central part of the Chicago metropolitan area.

Only one suitable site was found in the downtown Los Angeles CBD. The other five sites were "center-city" sites within the metropolitan region that had good data records. Like the other two cities, there were wide variations in sampling heights, from 4 to 100 ft.

In summary, the five or six sites selected in each city were centrally located and had the best data records that could be found for each city. However, the sampling height and the types of sites varied. The projected TSP levels for different sites should be examined individually in order to look at the effect of alternative scenarios at different locations within the central city.

5.4 ESTIMATES OF POPULATION EXPOSURE

One of the desirable methods of expressing pollutant levels is the population exposure analysis. According to Horie and Stern[30] the purpose of such an analysis is to describe the state of air quality representative of the population at risk.

For example, long term population exposure may be summarized in (a) a population average air quality which indicates the pollution level to which the population is exposed, (b) a health index which indicates the percentage of the population exposed to air pollution exceeding the primary National Ambient Air Quality Standard (NAAQS), (c) a welfare index which indicates the percentage of the population exposed to pollution exceeding the national secondary standard, or (d) a population dosage spectrum which indicates the distribution of the population associated with various air pollution dose levels. In this study, a population dosage spectrum was developed, as in (d), to express the increase in people exposed to higher levels of TSP in various future scenarios.

EPA has developed guidelines for population exposure analyses.[31] In this study the objective was to develop exposure distribution curves as illustrated in the EPA guidelines using data from the 1975 Trends Report.[32]

The methods used to develop population exposure profiles were straightforward, based on local conditions in the study areas. The first step was to review the monitoring sites that had been selected in each of the three cities for diesel impact analysis in order to determine whether these same sites could be used for a population exposure analysis. As described earlier, monitoring sites were chosen to represent CBD's where the greatest diesel impact was expected. The selection of sites based on diesel impact conflicts with the objective of a population analysis, wherein sites should be located on the basis of where the population will be exposed. Therefore, the population analyses were limited to those areas immediately adjacent to CBD's where both a population at risk and a high diesel impact were located.

One of the important criteria for the location of monitoring sites in a population exposure assessment is the density of the site network. The sites must be close enough together so that they may be considered representative of the ambient air breathed by the population at risk. The area represented by each monitoring site may be approximated by a circular area around the site.[31] The radius of this area depends upon the pollutant being monitored; the representative area for suspended particulate is said to be a 3-mile radius. This must be viewed as a crude approximation since it does not account for any meteorological factors. It is also a generous estimate of the size of the representative area since it is known that the TSP level in the ambient air can sometimes change within a few hundred feet of a monitoring site. Nevertheless, the EPA guideline is helpful in making a first order judgment about the adequacy of monitoring for population exposure to TSP.

In the metropolitan Los Angeles region, only one monitoring site is actually located in downtown Los Angeles (see Figure 5-1). Other monitors are located in adjacent communities which are generally considered part of the same city. The closest downtown site that was examined in this study was in Pasadena, 9 miles away. Other sites were located in Torrance (16 miles away) and Long Beach (18 miles away). The air monitoring system in Los Angeles is spread thinly over a very large area, which reflects the widely scattered population of the region. This network has been judged adequate for the study of oxidants, where the radius of representation is considered to be 10 miles. In fact, Horie and Chaplin[33] completed an extensive population exposure study of nitrogen dioxide and oxidants based on data from this network. Nevertheless, no cluster of sites in central Los Angeles can be chosen from this network such that the 3 mile areas around the sites will overlap. In other words, there will be substantial gaps between sites where the TSP levels to which the population is exposed is not measured. Certainly the handfull of sites selected for this study are not adequate for the usual treatment of population exposure, and it was not attempted.

However, an examination of the Los Angeles CBD showed that one statistical area was almost completely within the area of representation around the monitoring station. This area is designated "Regional Statistical Area No. 23" by the Southern California Association of Governments (SCAG) and is shown in Figure 5-1. In the 1970 census this area had a resident population of 90,416 people. Of these, 10.9% were of school age and 16.4% were over 65 years of age,[34] two age groups that are generally considered more susceptible to the harmful effects of air pollution. Portions of large statistical areas are also within the 3-mile radius, but data on the population at risk were not available.

SCAG population projections show that the area is expected to remain relatively stable, with population growth no more than 6% over the next 20 years.[35] (Recent trends actually show a decline.) Thus the increased TSP levels projected for the Los Angeles CBD under various scenarios may be interpreted as the exposure levels of approximately 90,000 people in Regional Statistical Area 23.

The monitoring sites in the central area of Chicago were also analyzed. Three sites were close enough together so that they represented a significant population at risk and could represent, to some degree, the variability of exposure within the area. As indicated in Figure 5-2, 12 statistical community areas designated by the City of Chicago, Department of Planning, City and Community Development, were found to lie within the overlapping areas of representation around each TSP monitor.

The EPA guidelines suggest a simple model for allocating the real measurements taken at monitors to imaginary receptor sites within designated population areas. Population areas are simply districts in which population data is readily available. The EPA model assumes a linear change in TSP levels between stations, but does not take into account any effects of meteorology. An equally accurate method is to assign the popu-

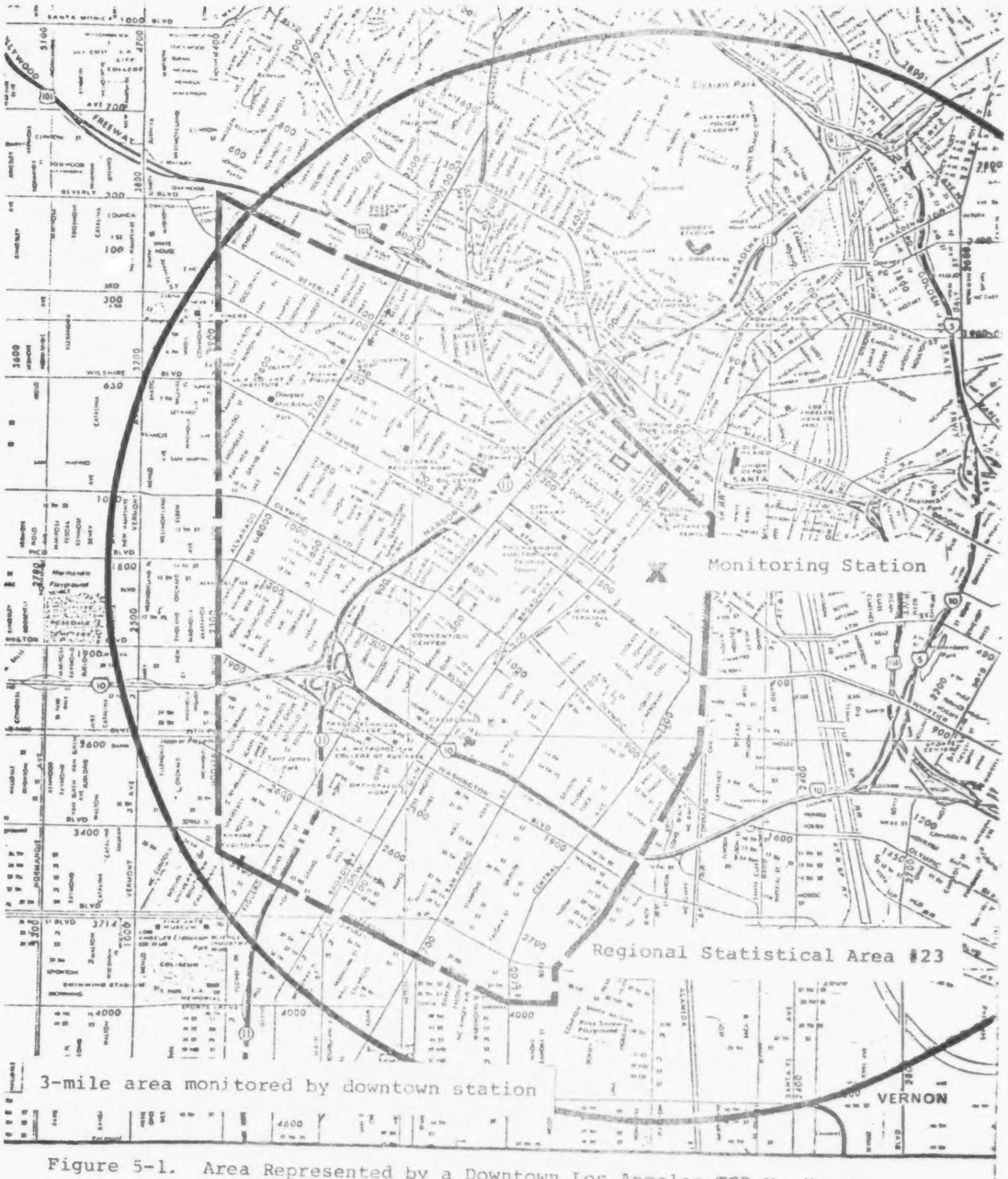

Monitoring Station
Regional Statistical Area #23
3-mile area monitored by downtown station
VERNON
Elysian Park
CONVENTION CENTER
WILSHIRE
WASHINGTON
BLVD

Figure 5-1. Area Represented by a Downtown Los Angeles TSP Monitoring Station.

lation areas to each monitoring site. Assignments should be made on the basis of proximity to monitors, local meteorology, buildings and topography, and historical patterns of TSP at these sites. This method may be more subjective because it used human judgment rather than a computer terminal, but it may also be more valid because it accounts for more of the factors which determine the representativeness of data from each monitoring station. On the basis of these assignments, the ambient TSP levels within community areas 3,4,5,6, and 7 were considered to be monitored by the station at Lakeview High School, 4015 N. Ashland. The ambient TSP levels within community areas 24, 27, and 28 were considered to be monitored by the station at Cook County Hospital, 1947 W. Polk St. The TSP levels in areas 8,32, and 33 were considered to be montored by the station at the G.S.A. Building, 538 S. Clark St. Thus, population areas were assigned to each of the three monitoring stations where TSP projections had been made.

Based on the above assignments, a dosage spectrum was estimated for the people at risk in the central area of Chicago. The following steps are presented in Appendix G, Table G-1. First, the projection year mean annual TSP level at each site was placed in order from the highest level to the lowest. The highest projected TSP level could be said to represent the exposure of the people in the population district assigned to that monitor. In 1980 the people in this district represented 12% of the total population of the three districts. Thus 12% of the population in the total area analyzed were projected to be exposed to an annual mean level of 81.1μg/m^3 in 1988 for Scenario $T_1D_1E_1$. The second highest projected for 1980 in Scenario $T_1D_1E_1$ was 78μg/m^3, and 37% of the total population being studied was assigned to this monitor. Thus it could be said that (12 + 39) or 49% of the total population under study was projected to be exposed to a level of 78μg/m^3 or higher. The lowest of the three mean annual levels for 1980 in Scenario $T_1D_1E_1$ was 66.8μg/m^3. Thus 100% of the population

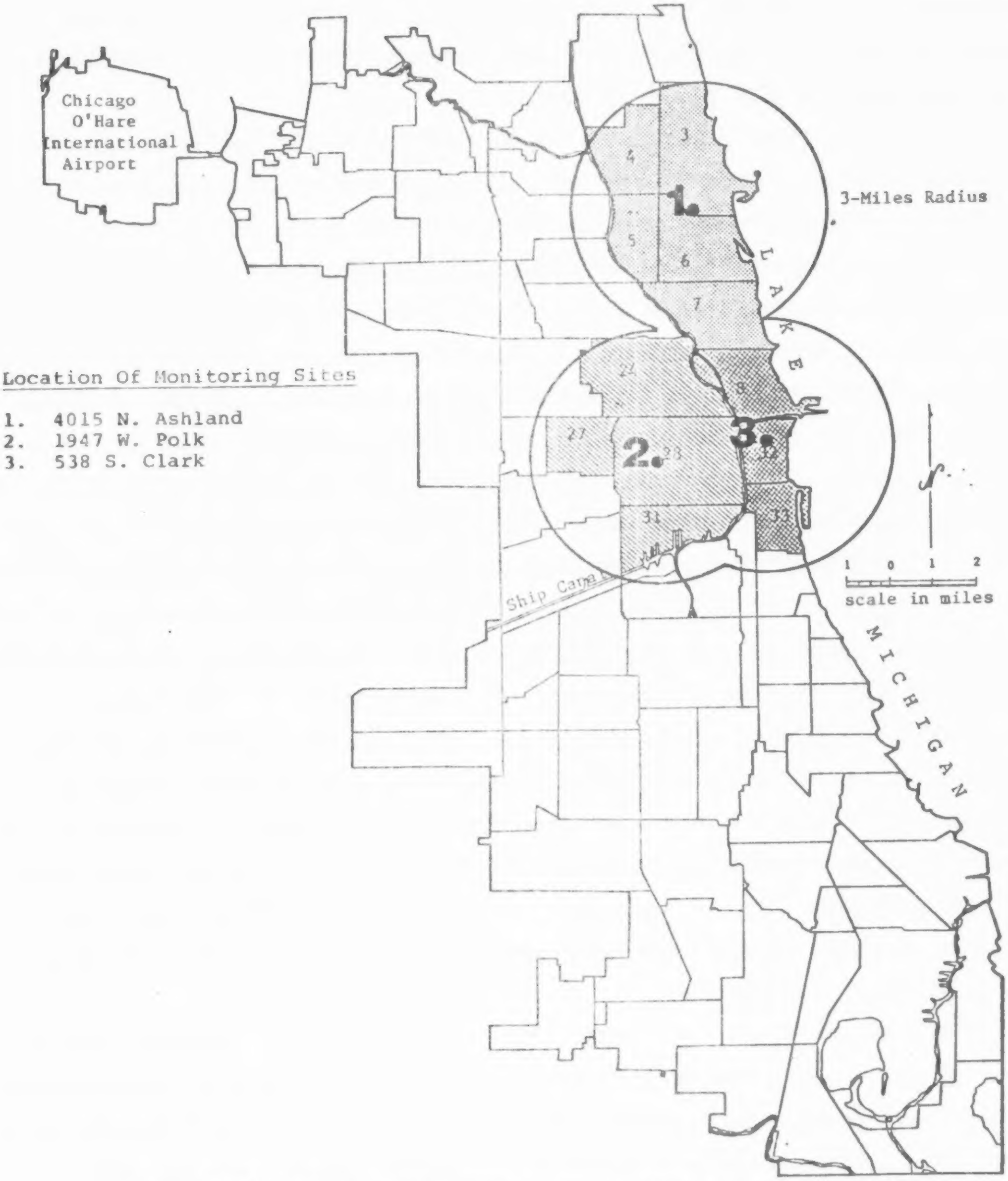

Chicago O'Hare International Airport
3-Miles Radius
LAKE MICHIGAN
Location Of Monitoring Sites
1. 4015 N. Ashland
2. 1947 W. Polk
3. 538 S. Clark
1.
2.
3.
3
4
5
6
7
8
24
27
28
31
32
33
Ship Canal
1 0 1 2
scale in miles

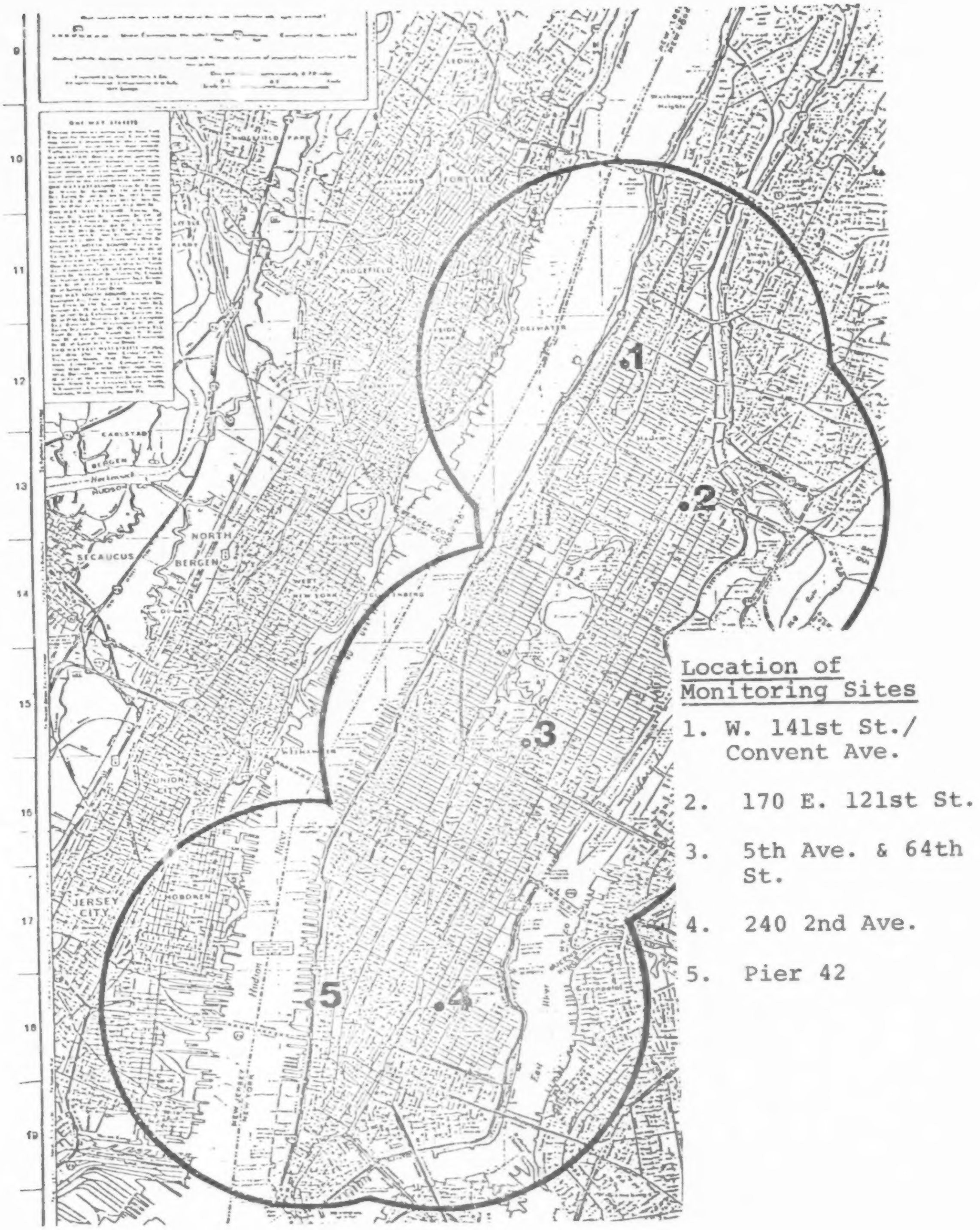
Figure 5-2. Areas Represented by Three Downtown Chicago TSP Monitoring Sites.

was projected to be exposed to an annual mean level of $66.8\mu g/m^3$ or greater. These three data provide the minimum number of points required for graphing a dosage distribution, as presented in the next chapter.

Note that the number of data points could be increased by establishing receptor sites within each community area and by assigning a portion of the measured TSP levels to each receptor site. This procedure would offer false security, because it would not increase the number of real measurements. Furthermore, the method of allocation from real measurements to receptor sites is based on assumptions that may or may not be valid. Rather than increasing the number of possibly false data points, the error margin inherent in graphically interpolating between too few data points was accepted.

In contrast to Los Angeles, Manhattan Island offered a density of monitoring sites that was appropriate for the analysis of population exposure to TSP. Five sites are located such that the 3-mile radius around the sites overlap considerably, as shown in Figure 5-3. The higher density of the monitoring network in New York parallels the higher density land use pattern. Not only does Manhattan Island represent one of the world's largest business districts, but it is also the home of over 1,400,000 resident New Yorkers. Thus the area provides a good basis for an analysis of population exposure to projected TSP levels.

The method used to establish the dose distribution was the same method as was used in central Chicago. Data on 289 census tracts previously developed for a regional 208 water study were used for the Manhattan analysis.[36] Each census tract was assigned to a monitoring station on the basis of proximity to monitors, local meteorology, buildings, topography, and historical patterns of TSP at the monitoring sites. These assignments resulted in 5 population exposure districts on Manhattan Island, as shown in Figure 5-4. Following the procedure previously described, the projected TSP levels were


LEONIA
Washington Heights
RIDGEFIELD PARK
FORT LEE
RIDGEFIELD
EDGEWATER
CARLSTADT
BERGEN
Hackensack
HUDSON
NORTH BERGEN
SECAUCUS
WEST NEW YORK
UNION
JERSEY CITY
HOBOKEN
Hudson River
East River
1
2
3
4
5
9
10
11
12
13
14
15
16
17
18
19

Location of Monitoring Sites

1. W. 141st St./ Convent Ave.
2. 170 E. 121st St.
3. 5th Ave. & 64th St.
4. 240 2nd Ave.
5. Pier 42

Figure 5-3. Area of Manhattan Island Represented by TSP Monitoring Sites.

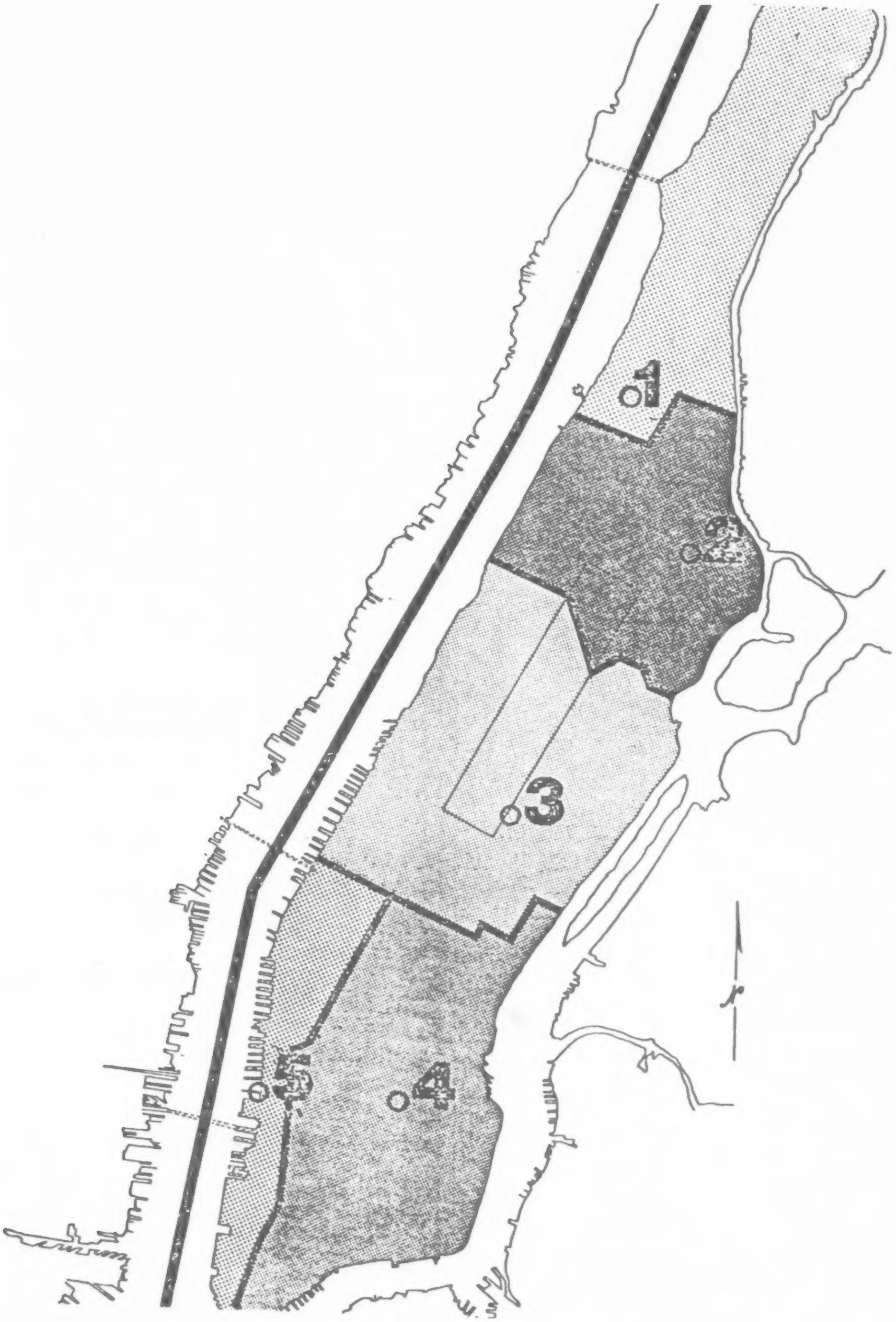


Figure 5-4. Population Districts Assigned to Each Monitoring Site on Manhattan Island.

rearranged so as to reflect percentiles of the population exposed. The population district associated with monitoring site 2 contained 280,090 people, or 19.3% of the total Manhattan population. The 1980 projected mean annual TSP associated with this district for Scenario $T_1D_1E_1$ was $72.8\mu g/m^3$, the highest projected level. Therefore 19.3% of the population are projected to be exposed to a level of $72.8\mu g/m^3$ in 1980 for Scenario $T_1D_1E_1$. In a like manner, the population within the population exposure district around each site was summed and the cumulative fractions obtained were associated with various projected TSP levels under alternative scenarios. The breakdown of fractions of the population exposed to various TSP levels is summarized in Appendix G, Table G-2. This table provides the data points for tracing the population dosage curves presented in the next chapter, "Results of Analyses."

Note that a constant population level is assumed for future projection years. Population projections that were carried out for the city of New York 208 water study indicate that Manhattan Island is expected to increase by only 1.3% by the year 2000.[37] Even this modest increase would be a reversal of recent trends tending to reduce the population. Thus, the assumption of a stable population was considered reasonable.

5.5 PROJECTIONS OF BAP

One of the secondary objectives of this project was to estimate the ambient levels of benza(a)pyrene (BAP) to be expected under various scenario conditions. BAP is one of the aromatic hydrocarbons found to be carcinogenic in test animals. Research is underway which will help determine what levels of exposure may be considered unhealthful for the human population. While no health criteria have yet been established, it was considered desirable to project BAP levels in the present study. When health criteria are established, these projections may be reexamined to determine whether or not they are within tolerable limits of safety.

The method used for the projection of BAP levels was based upon the previous work of others. First of all, it is known that some hydrocarbons tend to condense upon the surface of microscopic soot particles as they are dischared from a combustion source. BAP, an indicator species for the aromatic group, is considered to be associated with soot particles. From this observation alone one would expect to find definite ratios between BAP levels and TSP levels, since the majority of TSP is derived from various sources of combustion.

In a previous study, Briggs et al.[37] developed BAP/TSP ratios for the purpose of projecting BAP levels, given a projected TSP level. Based on various BAP studies, the ratios ranged from 2.15×10^{-6} to 12.29×10^{-6}. A mean ratio $(7.21 \times 10)^{-6}$ was adopted in order to make a single order-of-magnitude approximation under the alternative future scenarios. The use of a conversion ratio means that the BAP emissions from the transportation sector are estimated from the TSP emissions:

$$E_{TBAPY} = rE_y \tag{5}$$

where

E_{TBAPY} = the BAP emissions from the transportation sector in projection year Y,

E_y = the TSP emissions from the transportation sector in projection year Y, and

r = E_{BAPY}/E_Y, a dimensionless conversion factor when both emissions are expressed in the same units.

If the ratio r were assumed to be applicable to all emissions then we would have:

$$E_{BAPY} = rQ_y \tag{6}$$

where

E_{BAPY} = BAP emissions from all sources in projection year Y and

Q_Y = the sum of all TSP emissions in projection year Y.

If we substitute this expression into equation (2) and cross multiply, we have:

$$(7) \qquad r\bar{X}_y = E_{BAPY}k_B$$

This shows that the mean annual TSP levels are directly proportional to the BAP emissions. Conversely, the term $r\bar{X}_y$ can be taken to represent the BAP level. Thus, the projected BAP levels for each projection year and each scenario are obtained by multiplying the TSP levels by $r = 7.21 \times 10^{-6}$ and converting to ng/m^3. These projections are found in Appendix F, Table F-2.

Note that there is no obvious reason why the ratio r, which was developed for diesel emissions, should be applicable to all sources in the base year. However, when the TSP values found in New York and Los Angeles in the base year (from 62 to 104μg/m^3) are multiplied by r and converted to ng/m^3. The BAP levels 0.44 to 0.75 are obtained. This is within the range of BAP levels (0.3 to 3.5ng/m^3) found in cities by other investigators.[38] No definitive explanation for this observation is offered here; it will suffice to say that the projections are expected to yield reasonable results.

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6. RESULTS AND CONCLUSIONS

6.1 FUTURE TSP ESTIMATES

The previous chapters have discussed the design of the study, the use of scenarios, and the methods of relating emissions to air quality. The principal calculation steps used in this study have been summarized in Appendix E, "A Routine for Projecting Mean Annual TSP." After all the individual parameters and factors were calculated and tables of values established, the TSP projections for all the scenario combinations at all the monitoring sites were computed with the aid of a simple computer program. The projected normalized annual mean TSP levels are shown on Figures 6-1 to 6-16. The data represented by these figures are listed in Appendix F.

The most striking result displayed in these projections is the profound effect of the dieselization of the automobile population. Consistently, the cumulative effect of rapid dieselization (D_2 scenarios) is a substantial increase in the ambient level of particulate matter for all three cities and for all monitoring sites. For example, at Los Angeles site #1 the year 1999 TSP levels for all D_2 scenarios were estimated at 111 to 126$\mu g/m^3$ depending on which transportation scenario was used; this may be compared to a present normalized annual mean of 95$\mu g/m^3$. At New York site #2 the projected 1999 levels for D_2 scenarios ranged from 90 to 102$\mu g/m^3$, compared to a present normalized annual mean of 72$\mu g/m^3$. At Chicago site #3 the D_2 scenario projections were 97 to 109$\mu g/m^3$, compared to a present level of 81$\mu g/m^3$. In general, the TSP levels increased between 17% and 41% from 1978 to 1999 in the D_2 scenarios. Thus, it is apparent that all cities where the automobile contributes a significant portion of the ambient TSP will eventually experience a significant increase in TSP levels after the automobile population is switched to diesel.

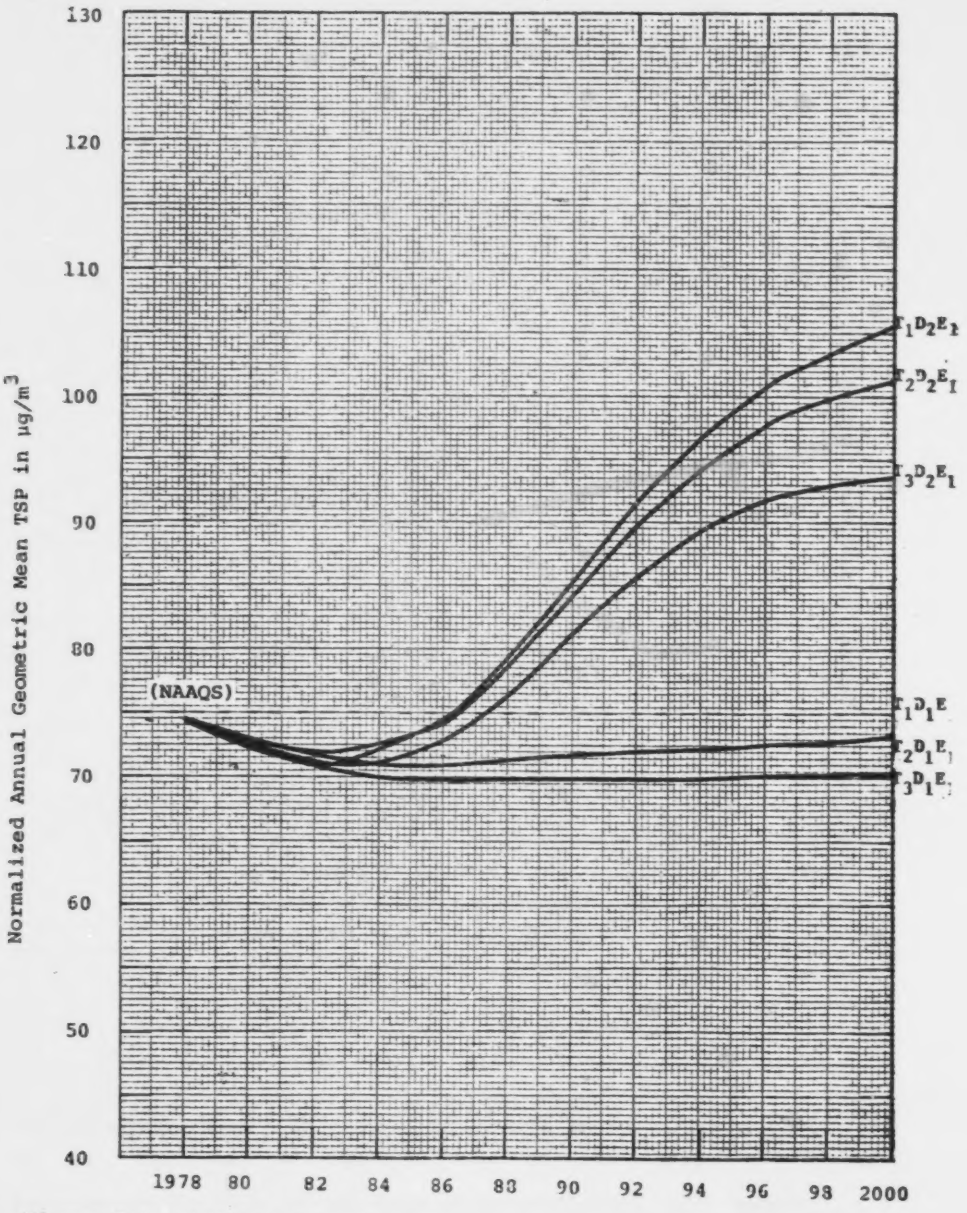

Figure 6-1. Projected Annual Mean TSP for N.Y. Monitoring Site at 170 E. 121 St.

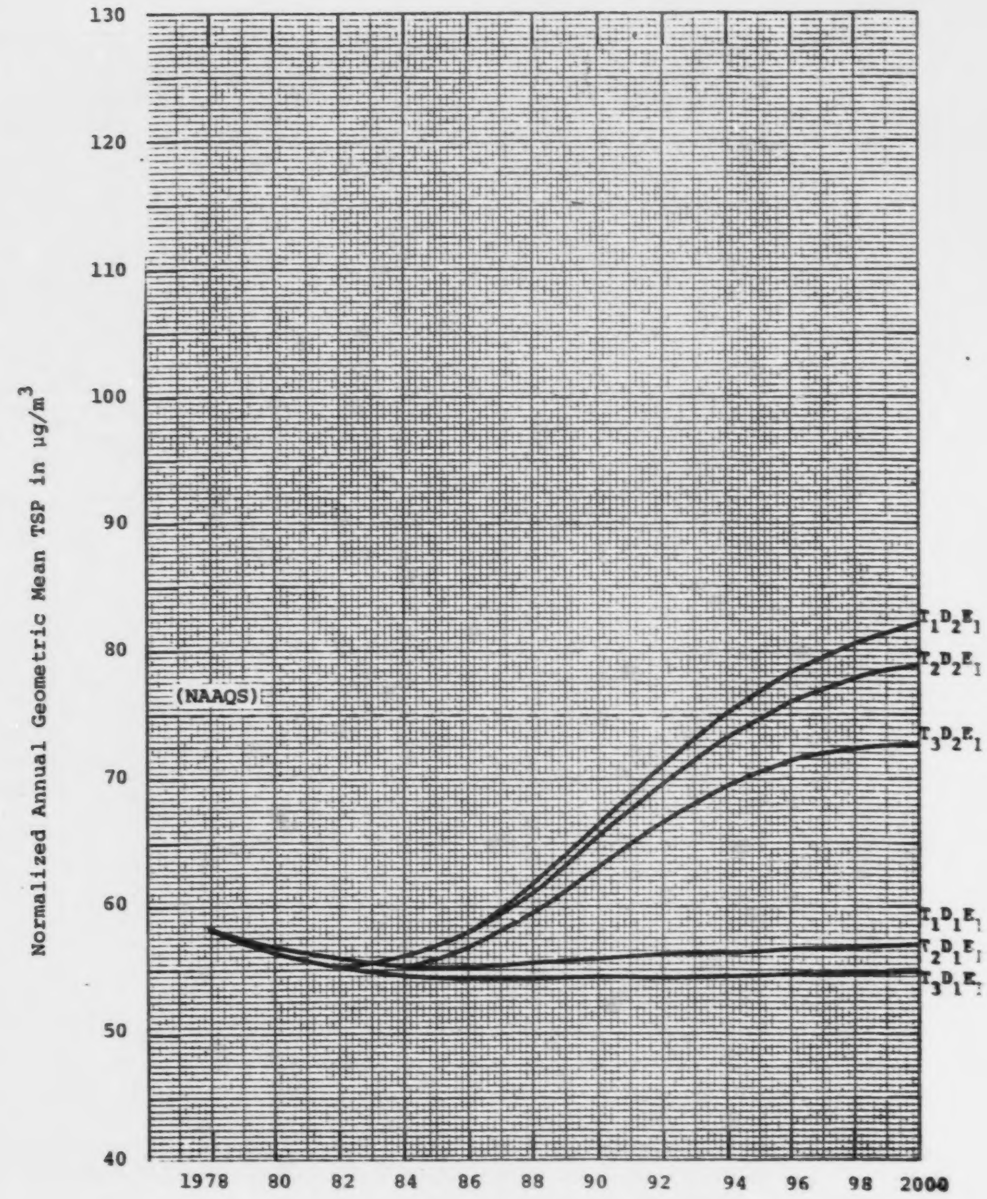

Figure 6-2. Projected Annual Mean TSP for N.Y. Monitoring Site at Pier 42, Morton St. and Hudson River.

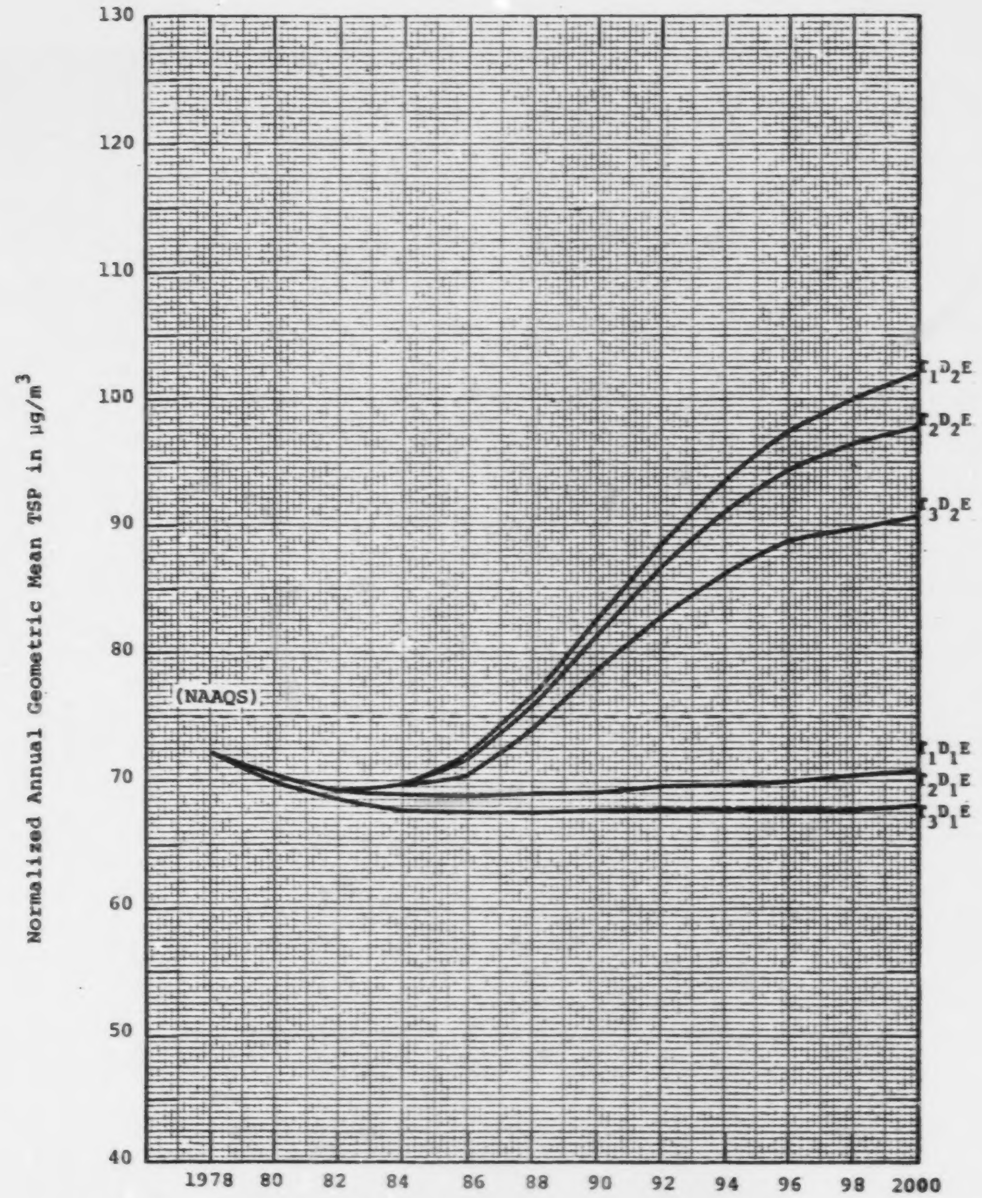

Figure 6-3. Projected Annual Mean TSP for N.Y. Monitoring Site at 240 2nd Ave.

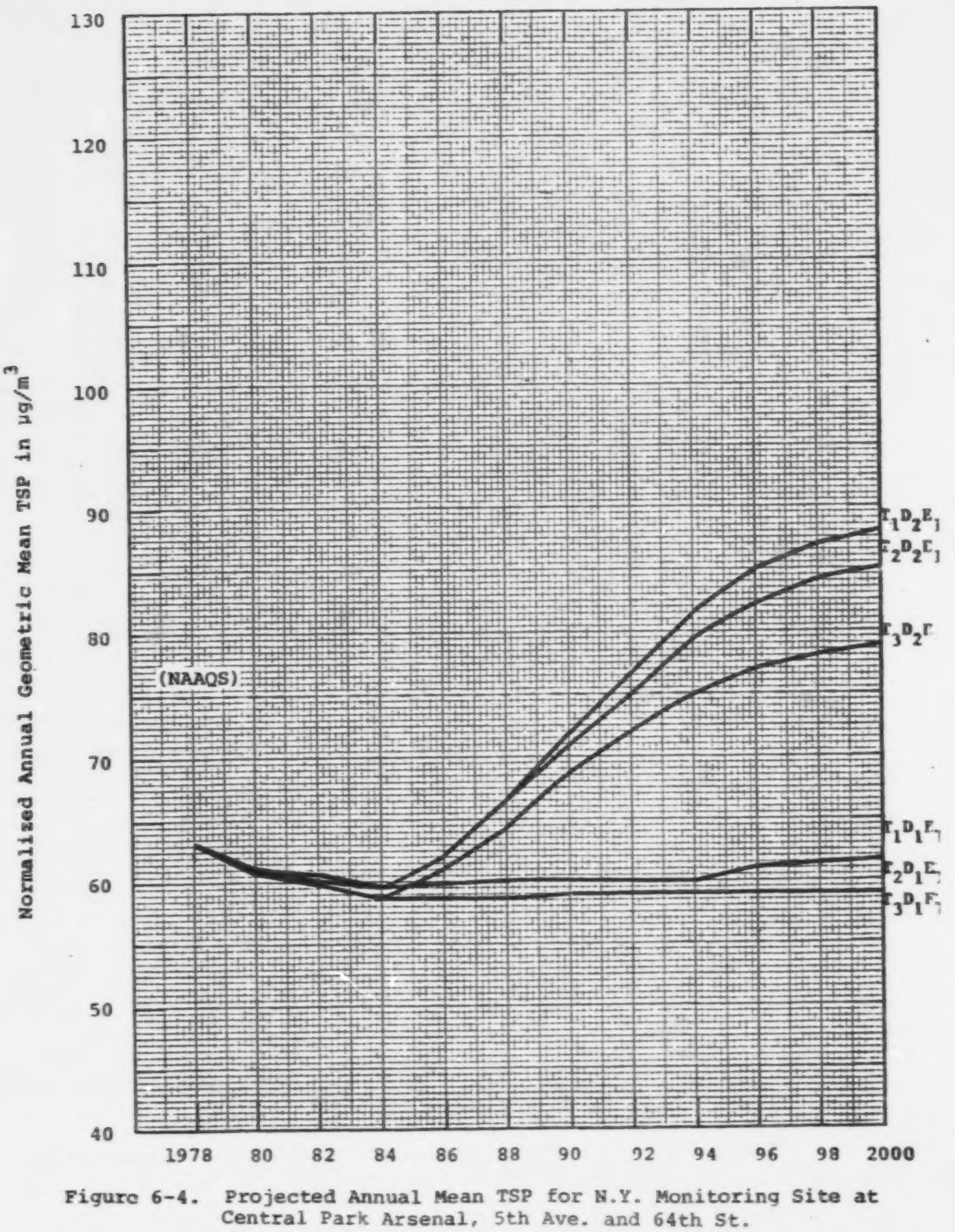

Figure 6-4. Projected Annual Mean TSP for N.Y. Monitoring Site at Central Park Arsenal, 5th Ave. and 64th St.

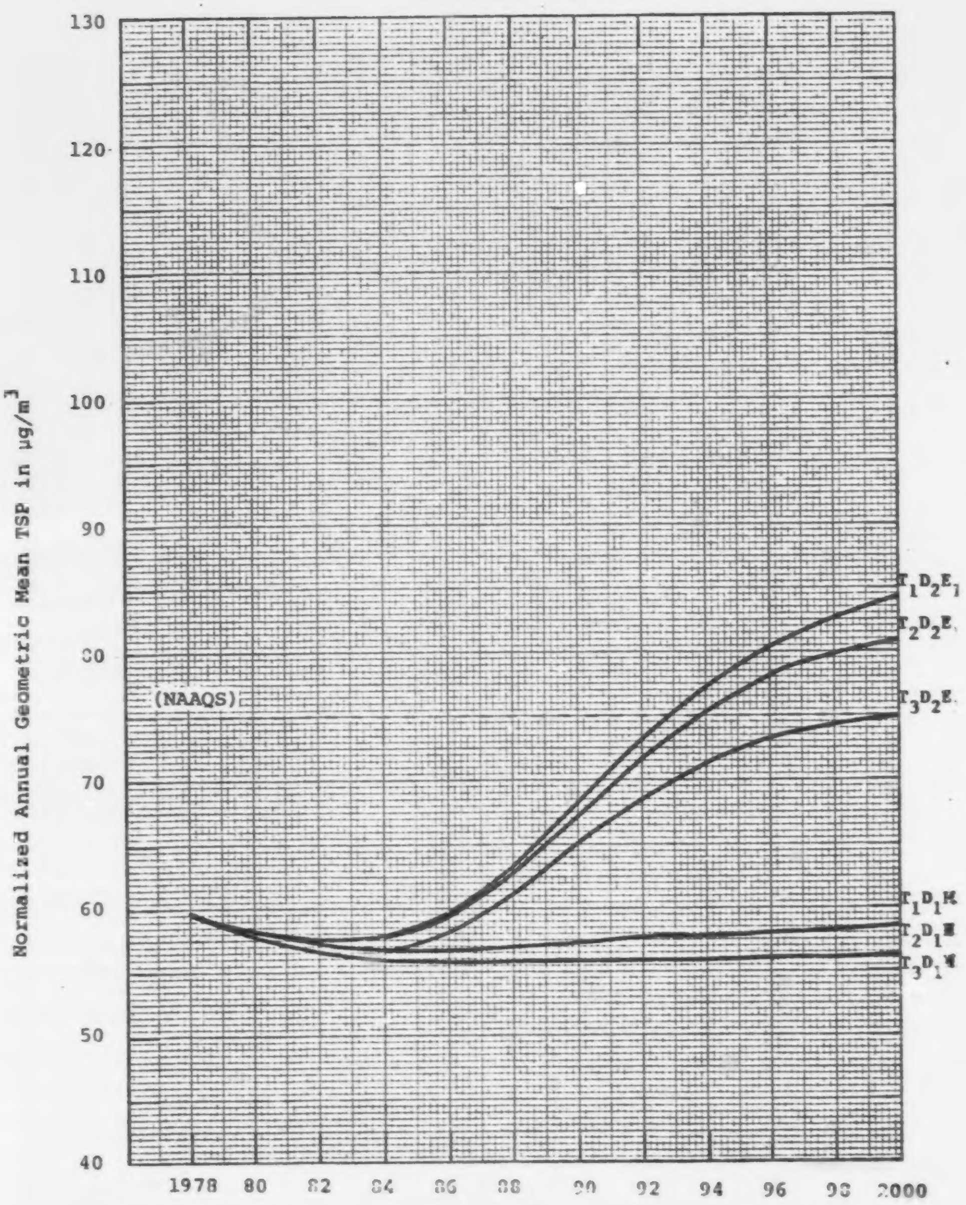

Figure 6-5. Projected Annual Mean TSP for N.Y. Monitoring Site at Steinman Hall, W. 141 St. and Convent Ave.

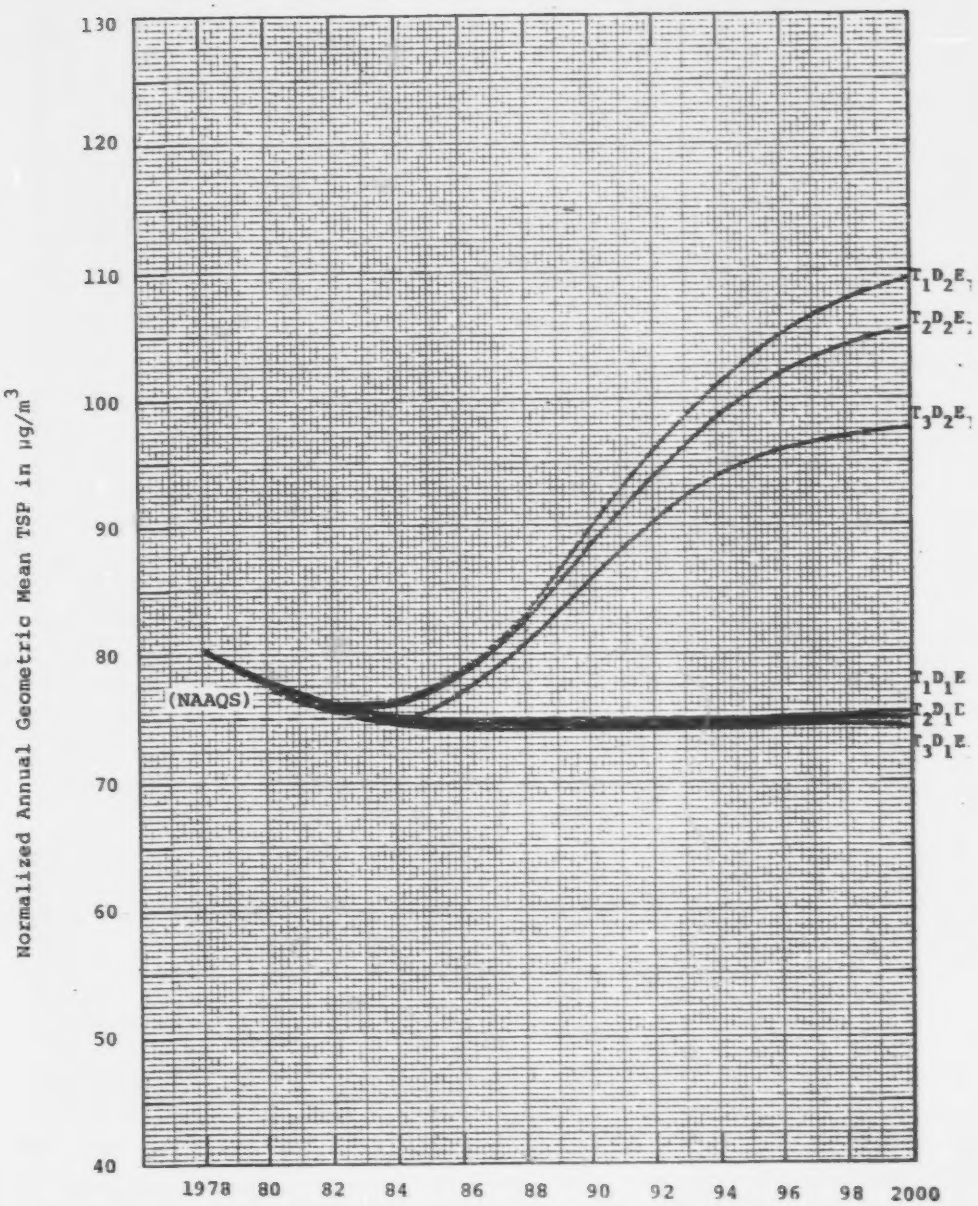

Figure 6-7. Projected Annual Mean TSP for Chicago Monitoring Site at 1947 W. Polk.

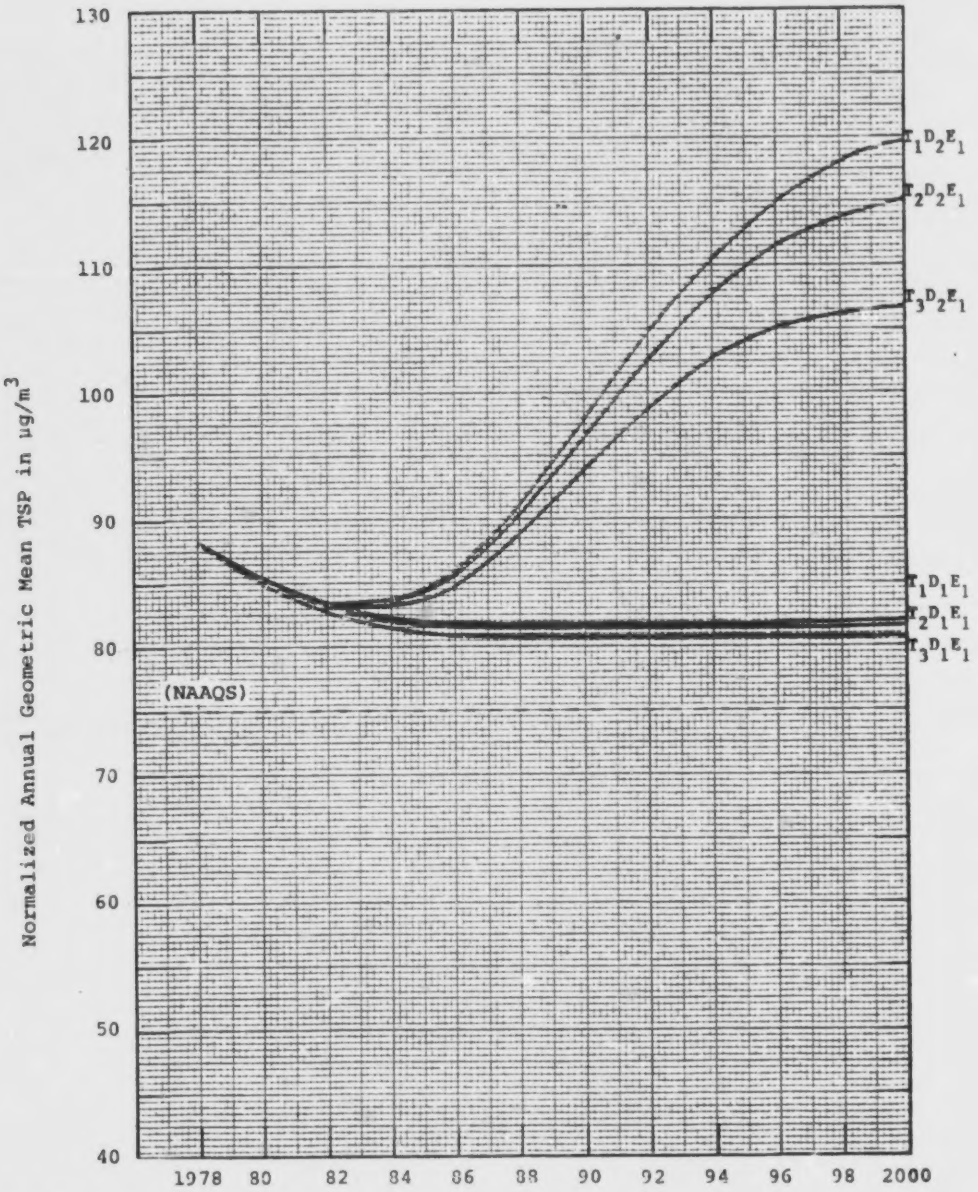

Figure 6-8. Projected Annual Mean TSP for Chicago Monitoring Site at 9800 S. Torrence Ave.

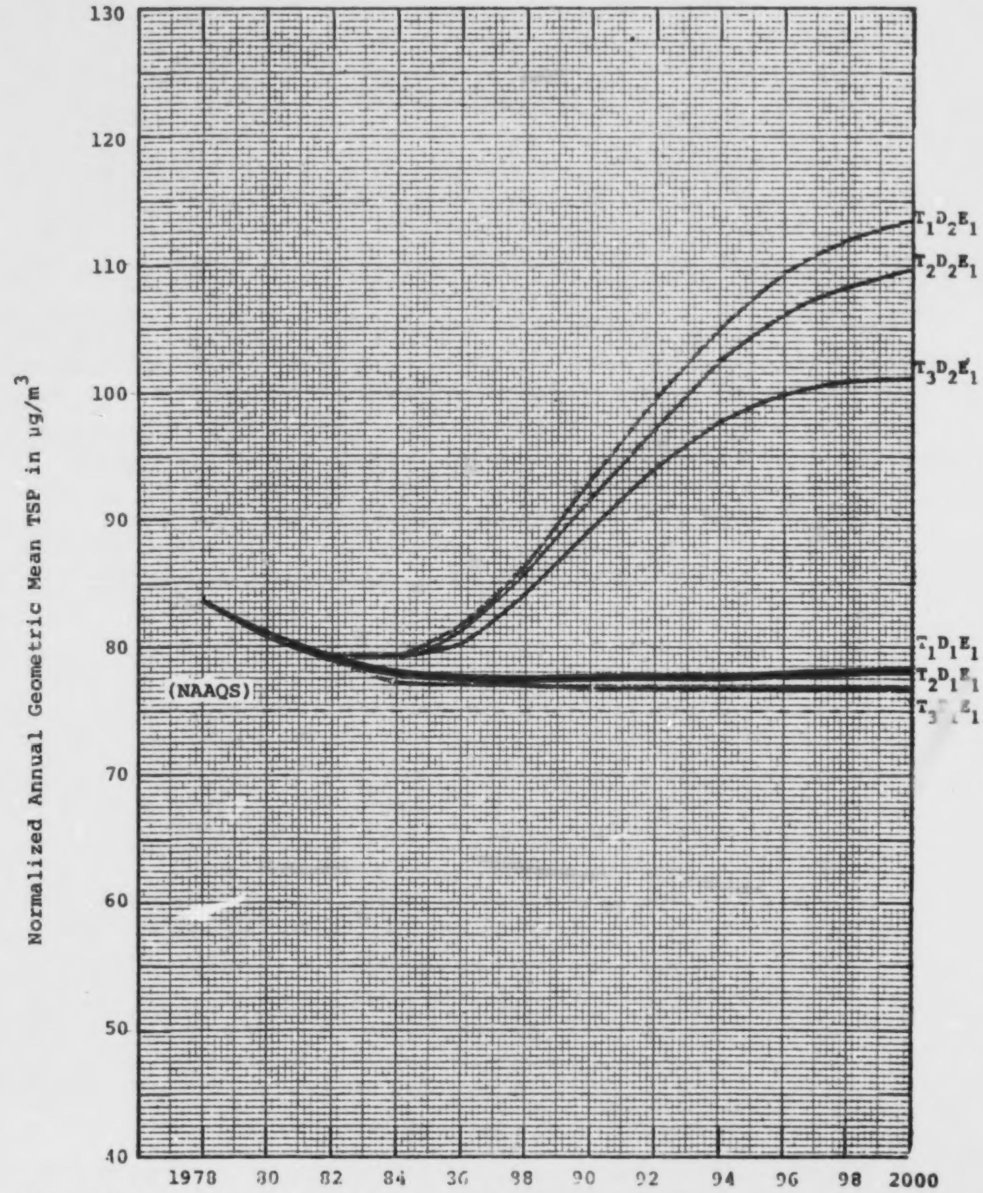

Figure 6-9. Projected Annual Mean TSP for Chicago Monitoring Site at 538 S. Clark St.

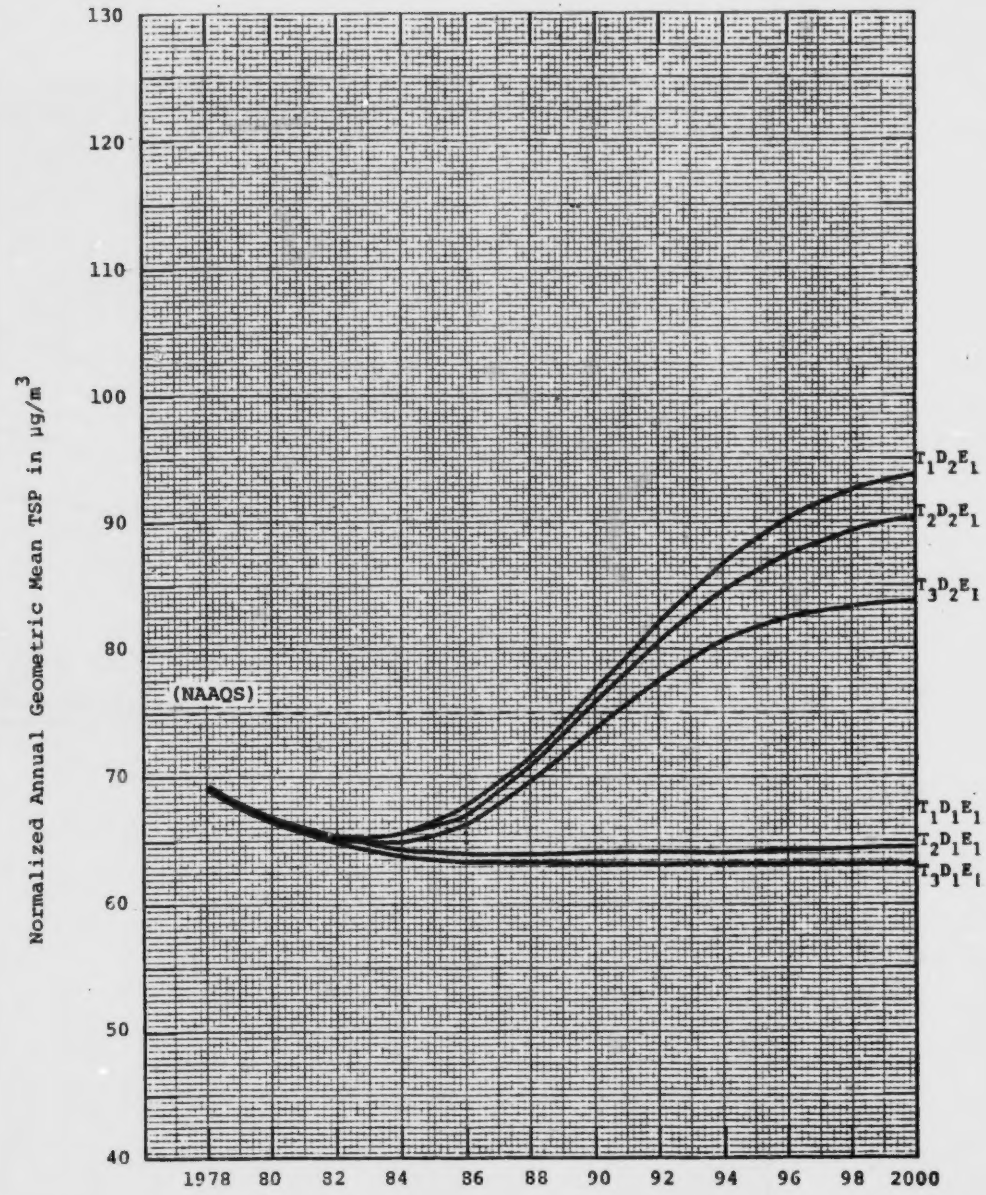

Figure 6-10. Projected Annual Mean TSP for Chicago Monitoring Site at 4015 N. Ashland Ave.

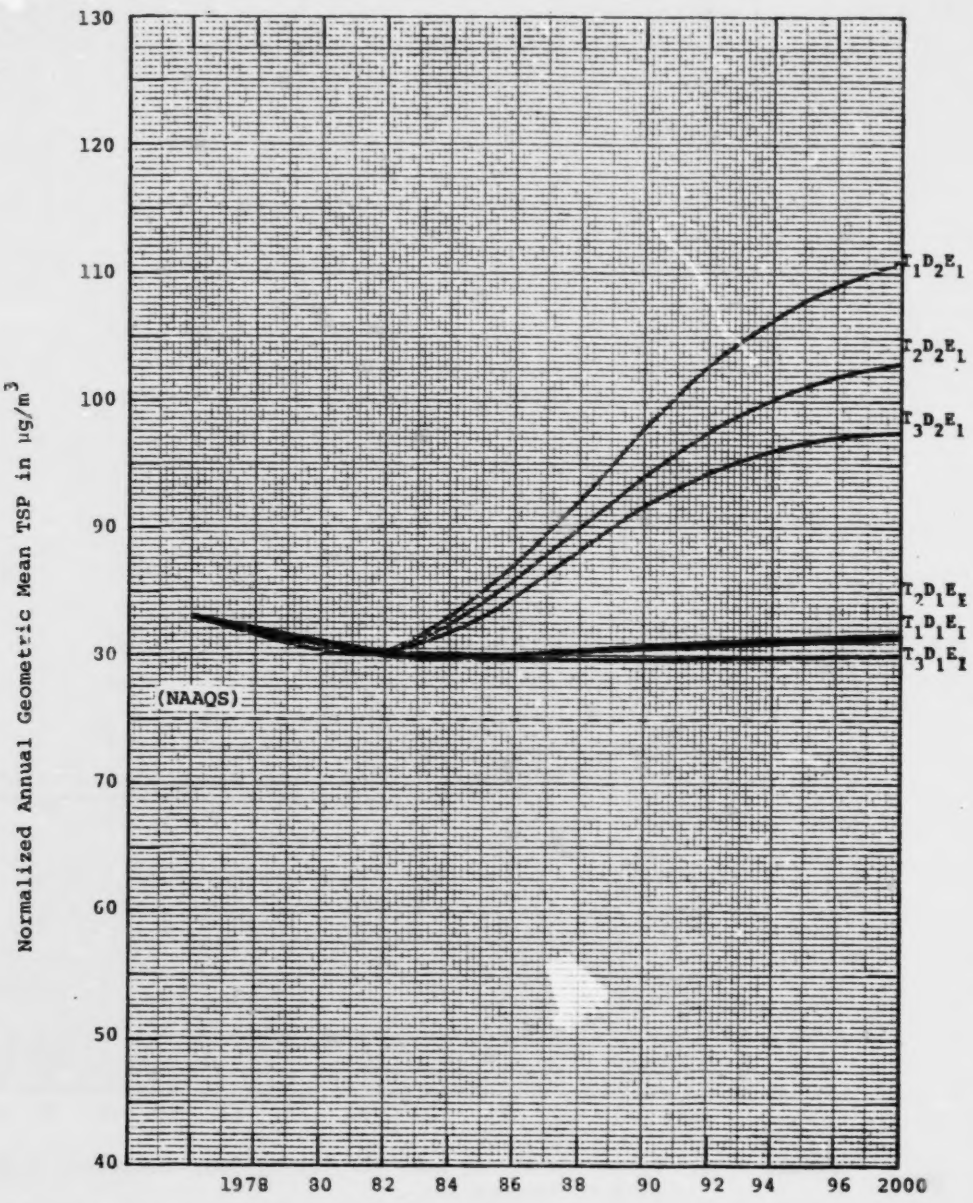

Figure 6-11. Projected Annual Mean TSP for Los Angeles Monitoring Site at 2300 Carson St., Torrance.

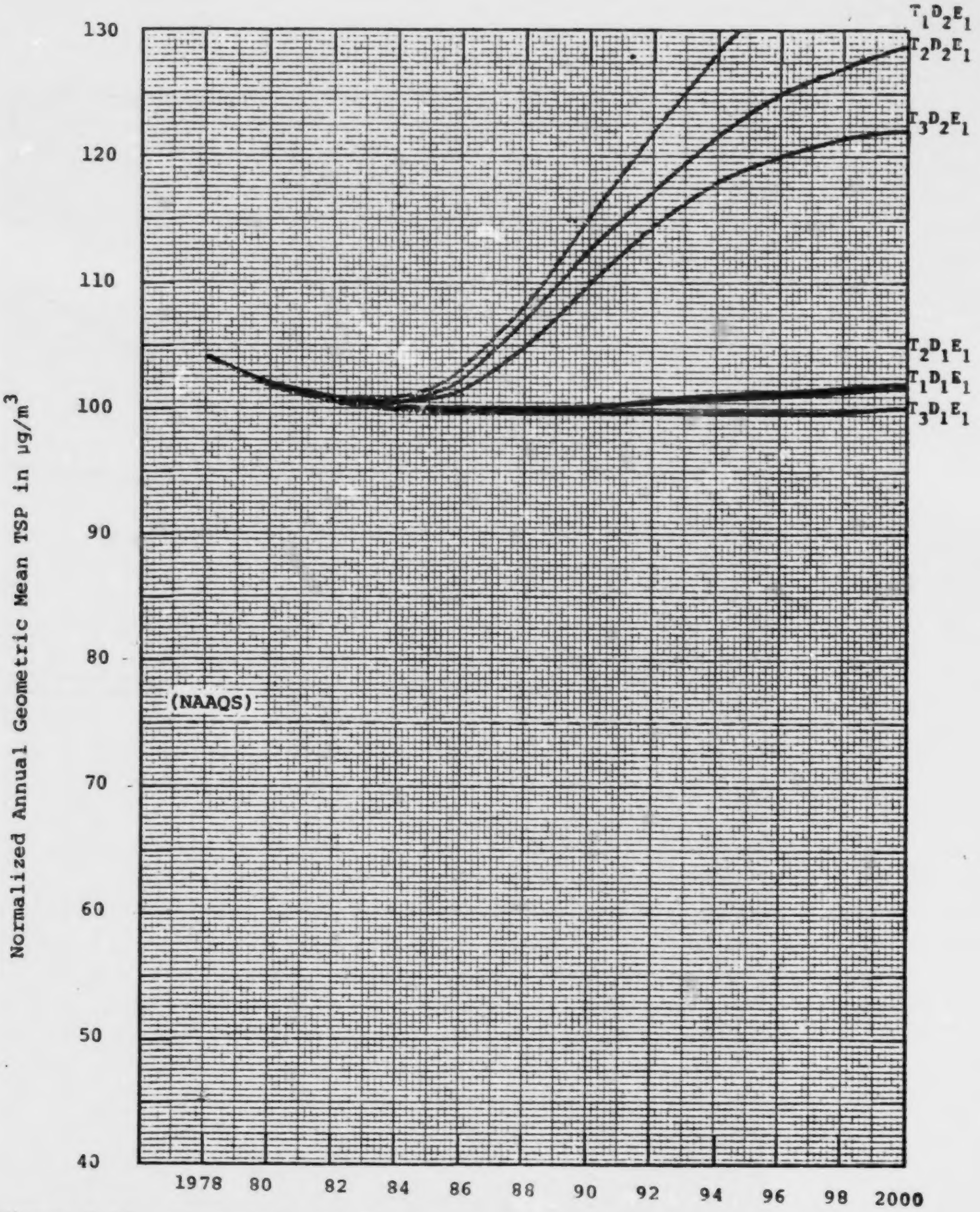

Figure 6-12. Projected Annual Mean TSP for California Monitoring Site at 434 S. San Pedro St.

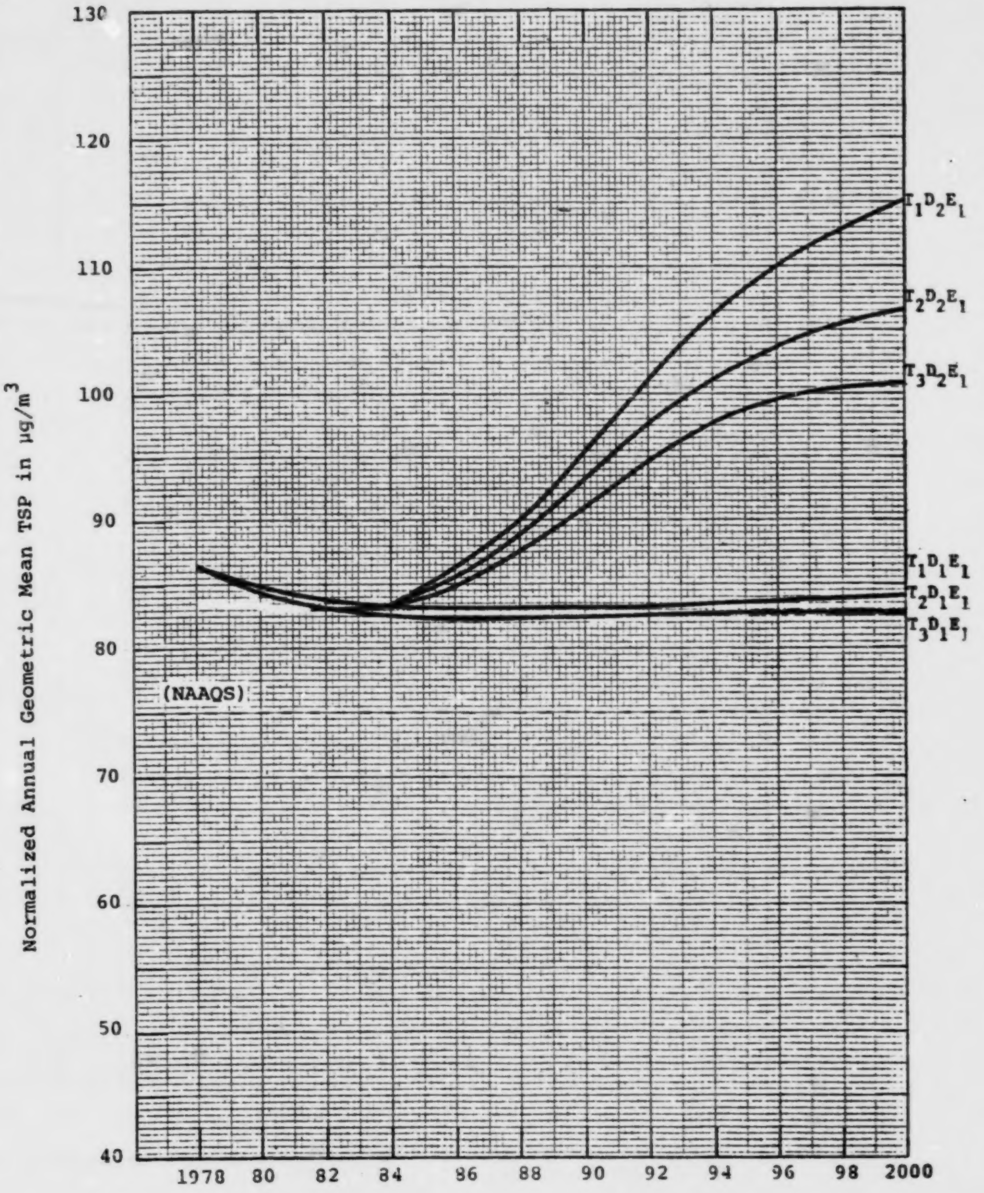

Figure 6-13. Projected Annual Mean TSP for California Monitoring Site at 2655 Pine Ave., Long Beach.

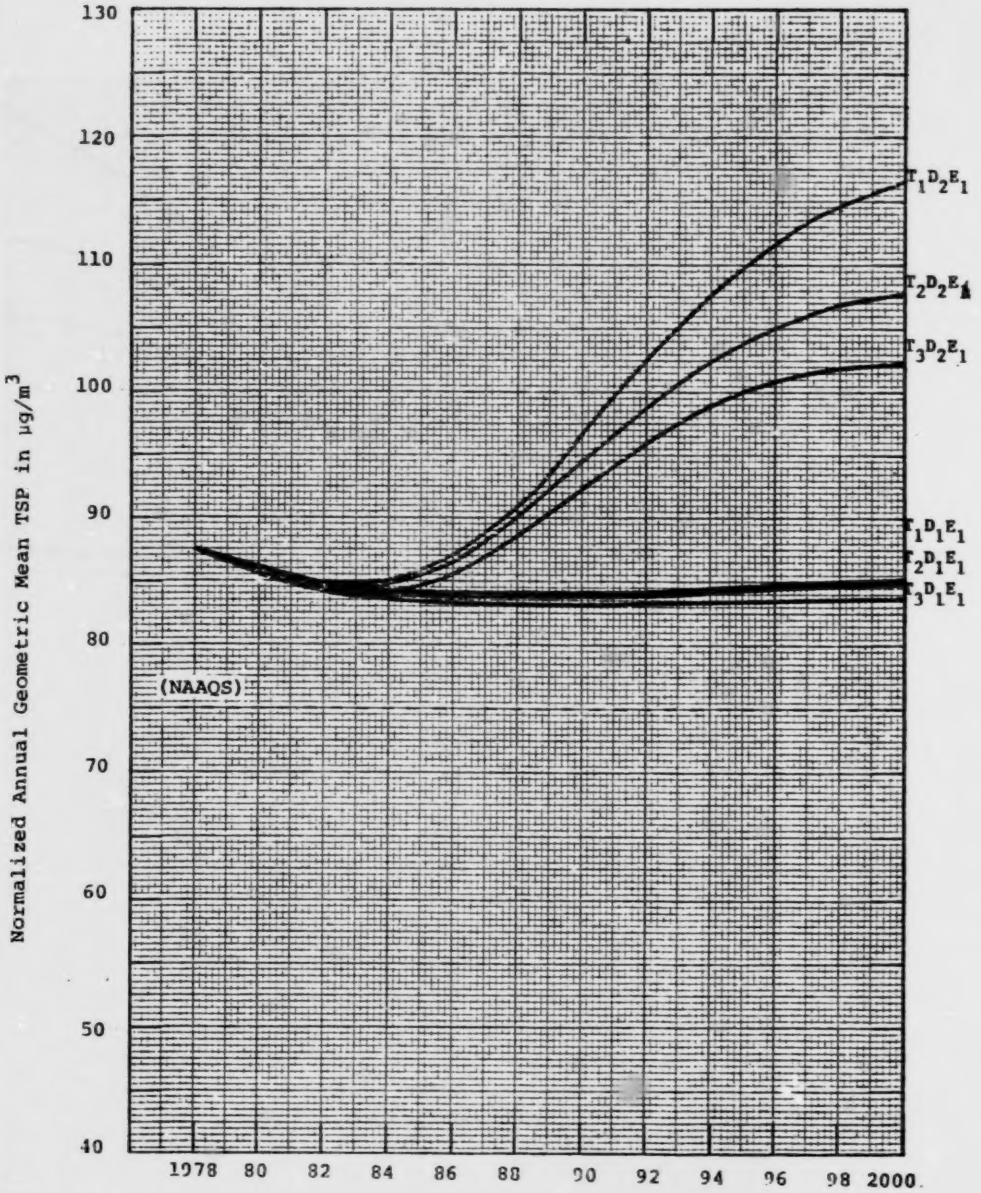

Figure 6-15. Projected Annual Mean TSP for Los Angeles Monitoring Site at Keck Laboratories, California Institute of Technology, Pasedena.

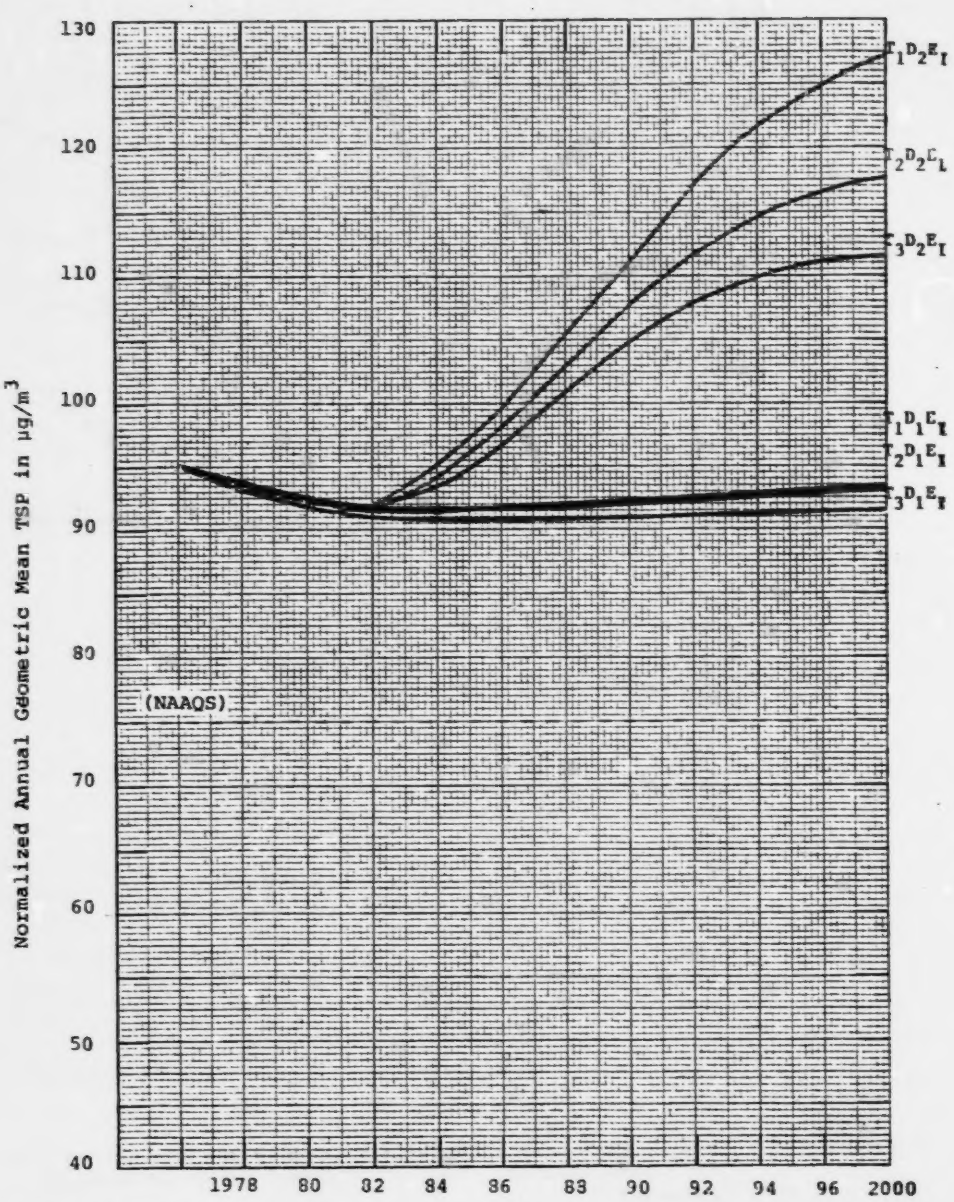

Figure 6-16. Projected Annual Mean TSP for Los Angeles Monitoring Site at 11408 La Cienega Blvd., Lennox.

One aspect of the projected ambient TSP levels is the fraction that is respirable. We cannot know this with certainty without studying the particle size distribution in the base year. However, we can easily estimate the diesel contribution from the transportation sector which is significant because it is definitely known to be respirable. The estimated diesel contribution to TSP in the 1999 D_2 scenarios were 15-21$\mu g/m^3$ in New York, 14-20$\mu g/m^3$ in Chicago, and 13-18$\mu g/m^3$ in Los Angeles. The exact contribution depended upon which monitoring site and which transportation scenario was used.

Another interesting aspect of these projections is the short-term decrease in TSP levels. Regardless of which scenario combination was chosen, there was a net decrease in ambient TSP levels from 1978 to 1984 due to a reduction in particulate emissions from motor vehicles. This phenomena should probably have been expected from the low particulate emissions factors that are associated with current models of vehicles. The table of travel-weighted emission factors in Appendix D shows clearly how the automobile population gradually becomes non-polluting in terms of particulate emissions. In the non-diesel automotive (D_1) scenarios the low particulate emissions continue throughout this century. In the diesel (D_2) scenarios the travel-weighted particulate factors increase substantially, and by 1995 they are over 50 times greater than the factors for that year in the D_1 scenarios.

This study was carefully constructed to measure the impact of alternate transportation systems on future TSP levels. It is ironic, therefore, to observe how little difference the transportation alternatives make in all D_1 cases. These projections show that changes in the modal choices will not substantially alter the particulate contribution as long as the TSP emission factors remain low. This result is consistent with other estimates of the impact of transportation controls. For example, in Chapter 2 it was shown that very little carbon monoxide emissions reduction could be achieved in New York through a transportation program, compared to the profound effects of a national automobile emissions control program (see Figure 2-8). On the other hand, if the TSP emission factors become higher, such as in the D_2 scenarios, then the effects of modal choice become important.

If scenario T_2 (Moderation) were taken to represent the effects of local programs to reduce automobile usage, then the difference between scenarios T_1 and T_2 might approximate the results that could be expected from such programs. These "reductions" would represent as much as 3-10$\mu g/m^3$ by year 1999. (It is difficult to call these differences "reductions" since all the monitoring sites continue to show increased TSP levels in the T_2D_2 scenario combinations.) If more pronounced changes in modal choice were to take place, such as in the T_3 scenarios, then an important part of the adverse effects of diselization would be averted. The differences between the T_1 and T_3 scenarios would be about 9-15$\mu g/m^3$ by the year 1999. However, it must be recalled that substantial changes in modal choice probably cannot be made without some adverse effects in the present economy. Scenario T_3 might be the result of oil crises, recessions, or restrictions on automotive choice. It is well to remember that a man without a job to pay his bills might not be too impressed with his reduced potential for contracting emphysema.

6.2 POPULATION EXPOSURE

Another way to look at the projected effects of diesel on air quality is through population exposure. Figures 6-17 through 6-25 show the changing distributions of the exposure to higher TSP levels in the central areas of Chicago and New York, the two cities where the variability of exposure could be measured.

In Chicago, the population in the central area of the city is presently exposed to a TSP that is close to the national ambient air quality standard of 75$\mu g/m^3$. Figure 6-17 shows the projected TSP exposures for the near term (1980) and for the

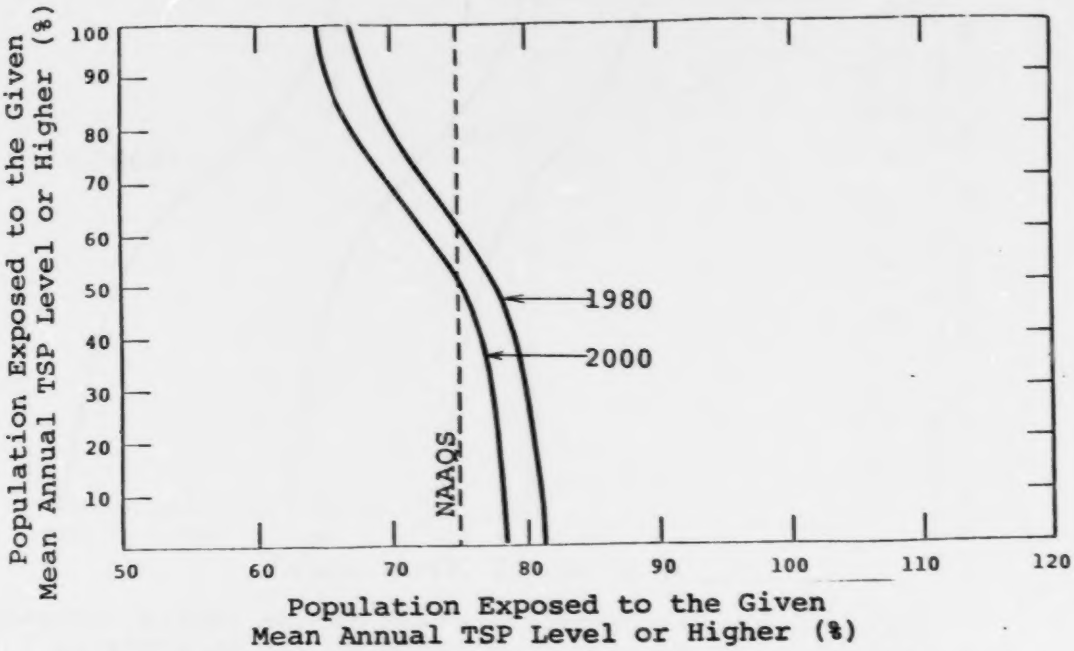

Figure 6-17. Projected Decrease in the Central Chicago Population Exposed to TSP in Scenario $T_1D_1E_1$.

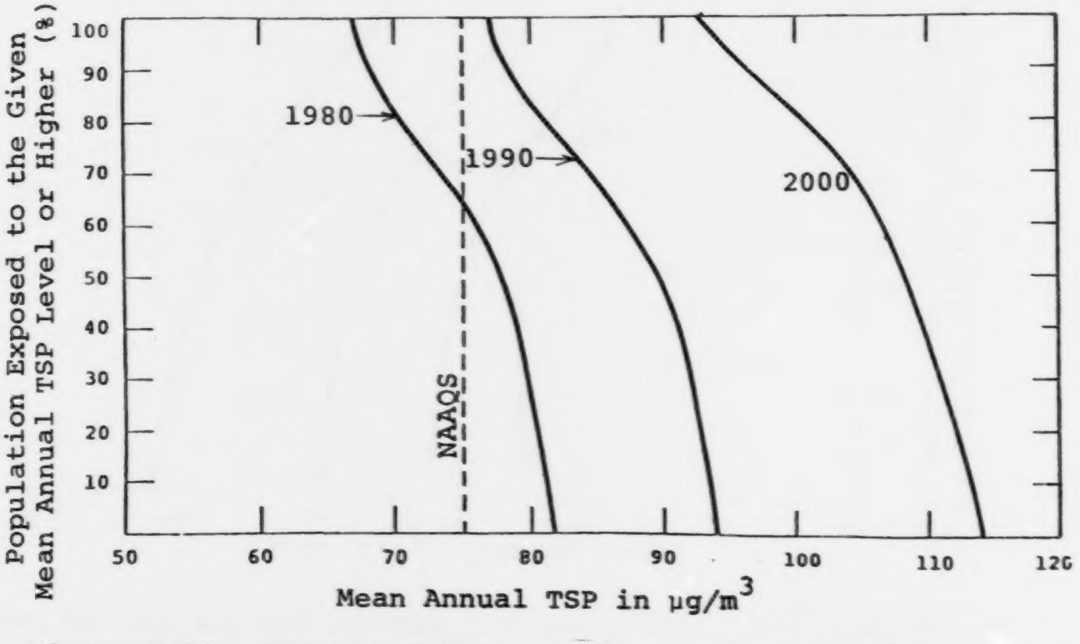

Figure 6-18. Projected Increase in the Central Chicago Population Exposed to TSP in Scenario $T_1D_2E_1$.

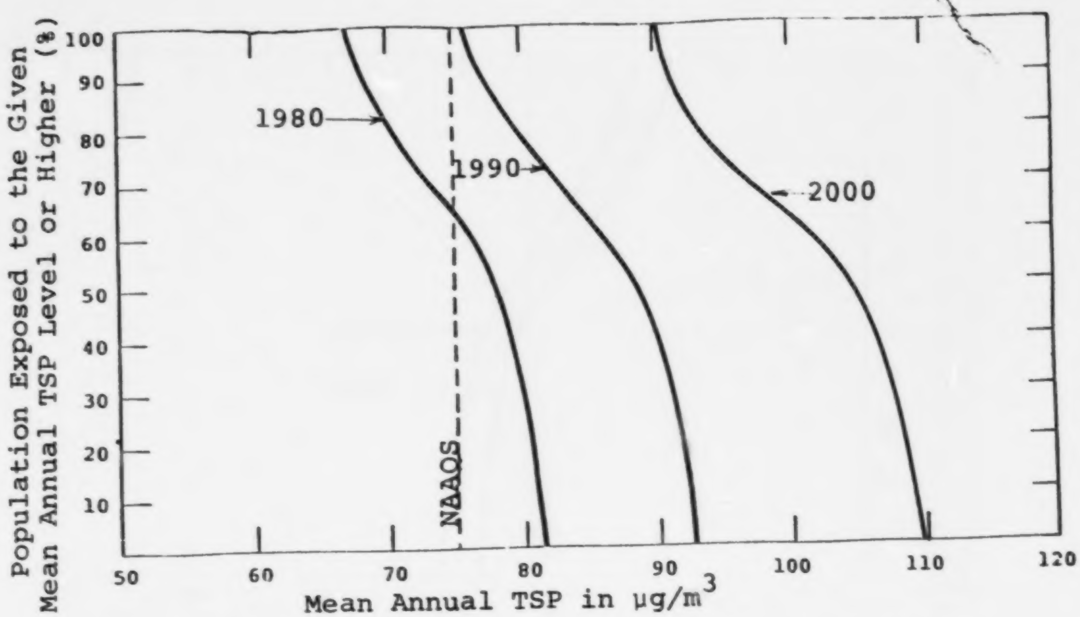

Figure 6-19. Projected Increase in the Central Chicago Population Exposed to TSP in Scenario $T_2D_2E_1$.

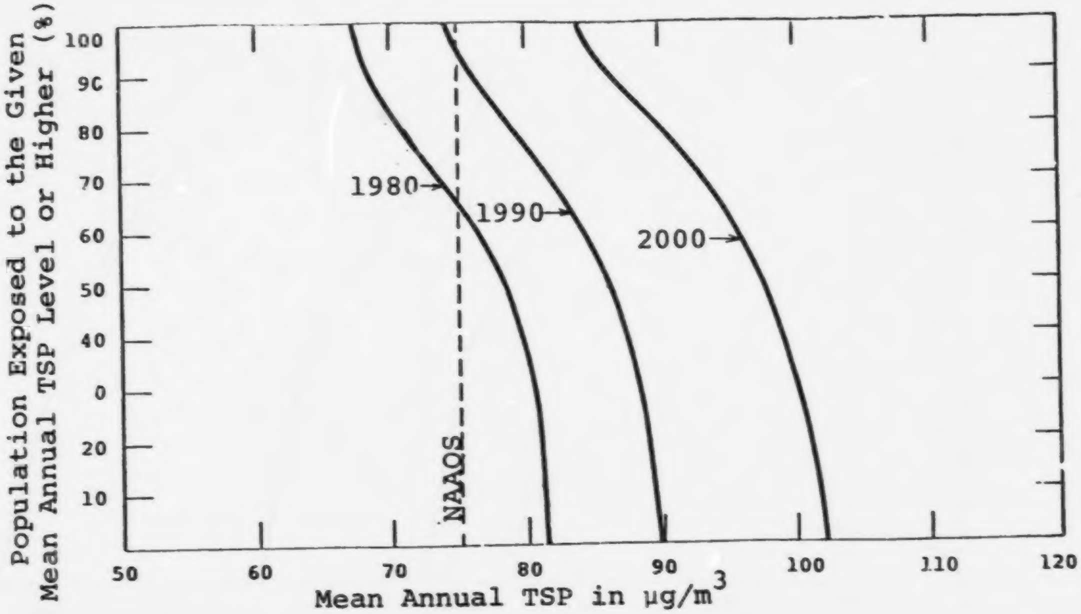

Figure 6-20. Projected Increase in the Central Chicago Population Exposed to TSP in Scenario $T_3D_2E_1$.

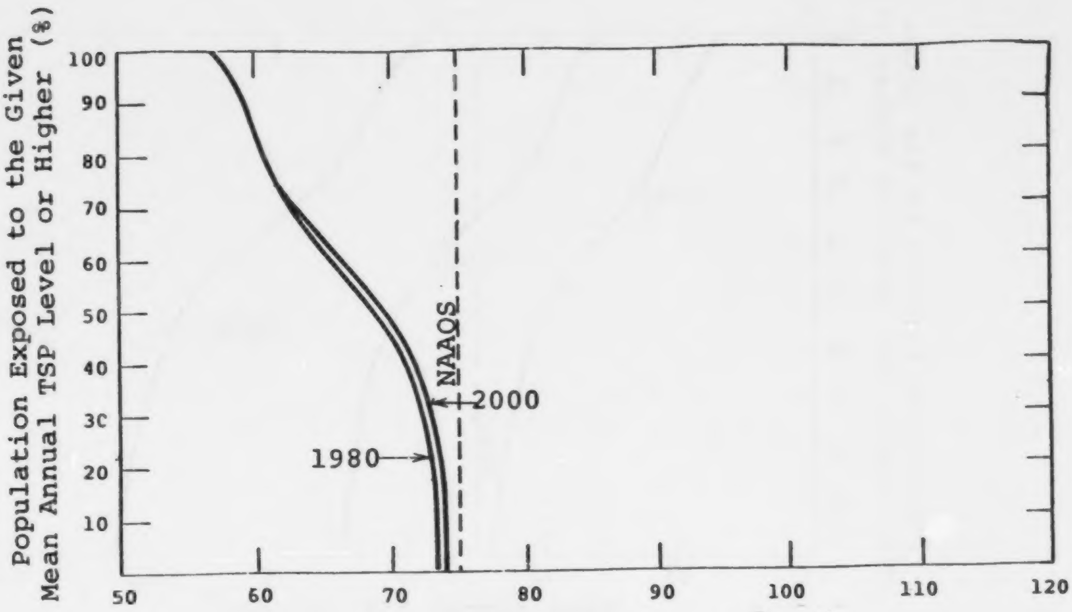

Figure 6-21. Projected Increase in the Manhattan Island Population Exposed to TSP in Scenario $T_1D_1E_1$.

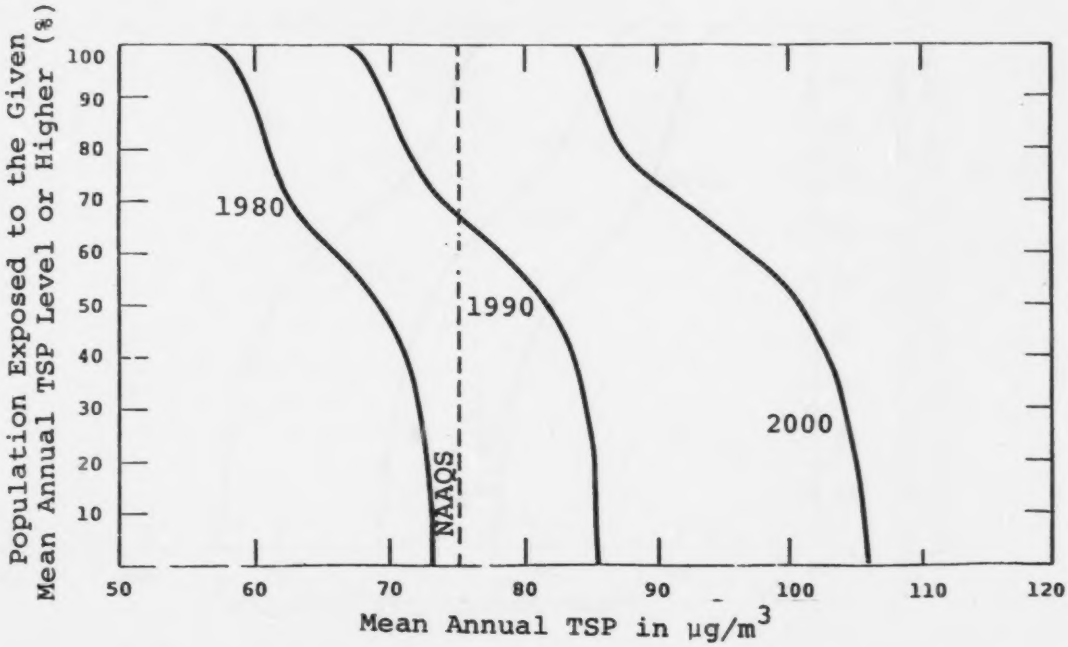

Figure 6-22. Projected Increase in the Manhattan Island Population Exposed to TSP in Scenario $T_2D_1E_1$.

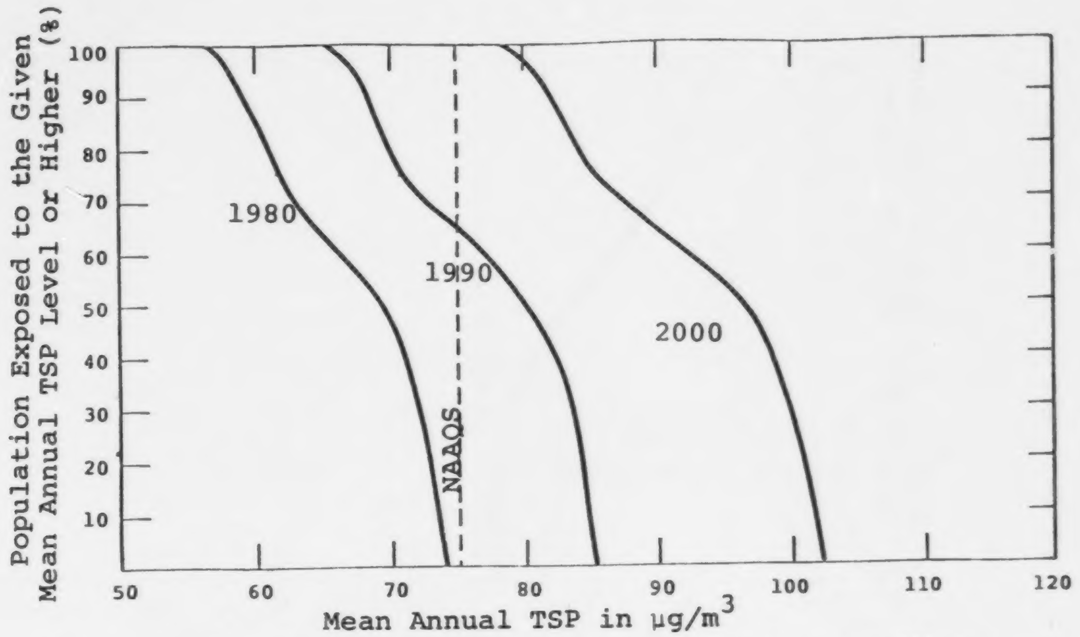

Figure 6-23 Projected Increase in the Manhattan Island Population Exposed to TSP in Scenario $T_2D_2E_1$.

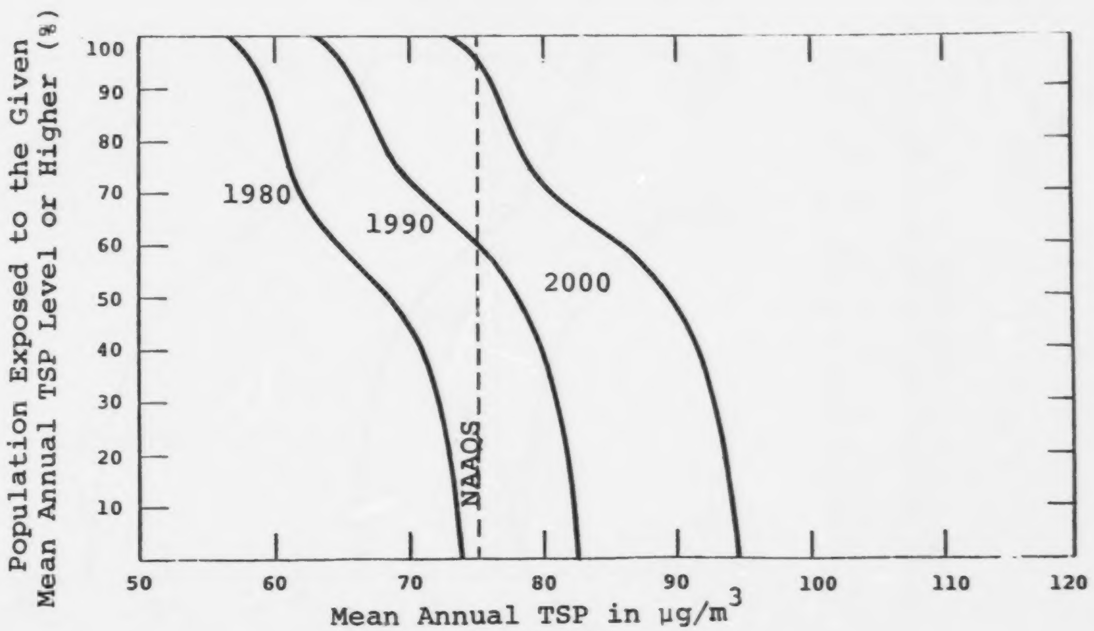

Figure 6-24. Projected Increase in the Manhattan Island Population Exposed to TSP in Scenario $T_3D_2E_1$.

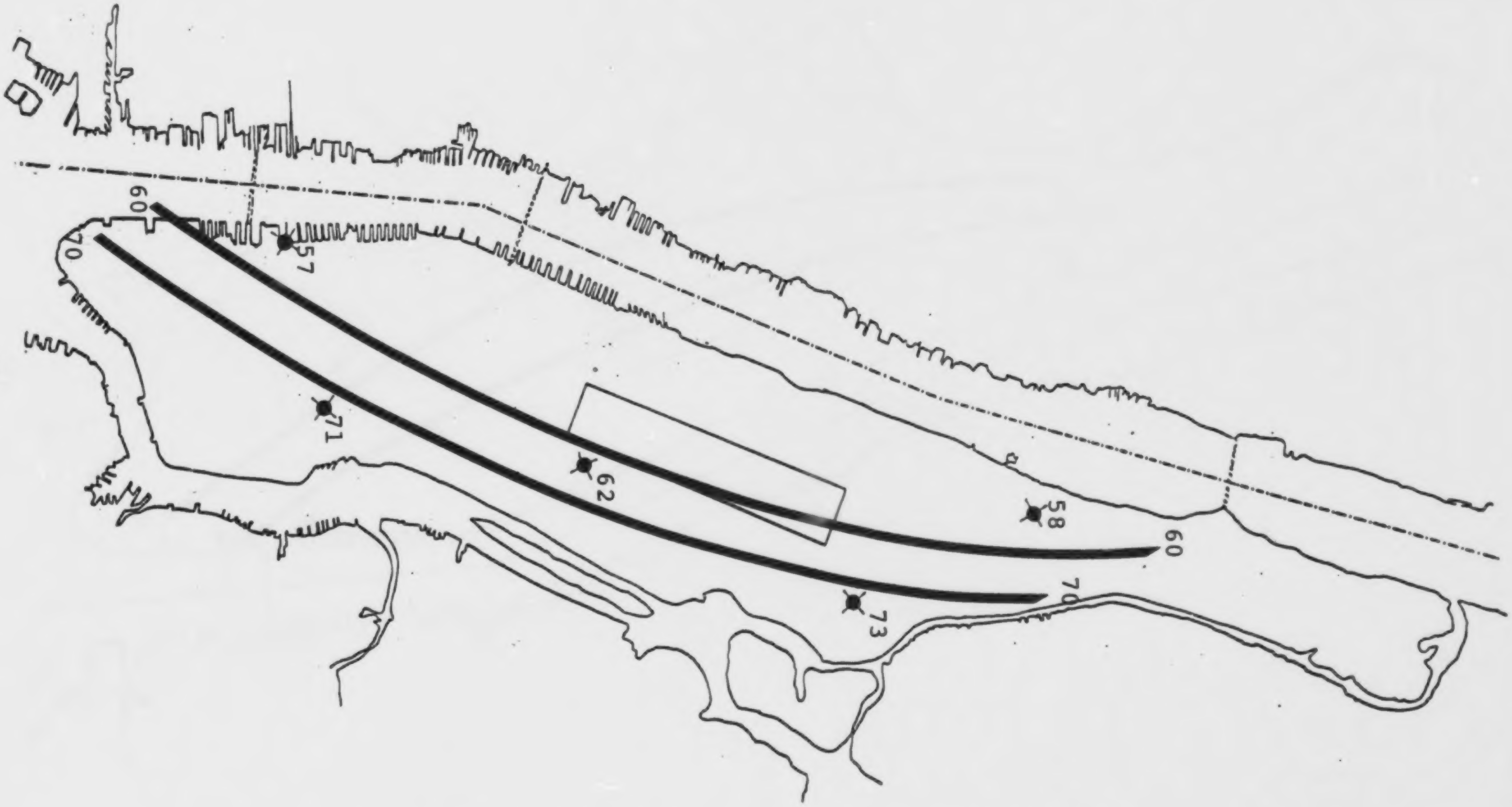
60
70
57
71
62
58
60
73
70

Figure 6-25. Year 1980 Projected TSP Distribution on Manhattan Island (All Scenarios).

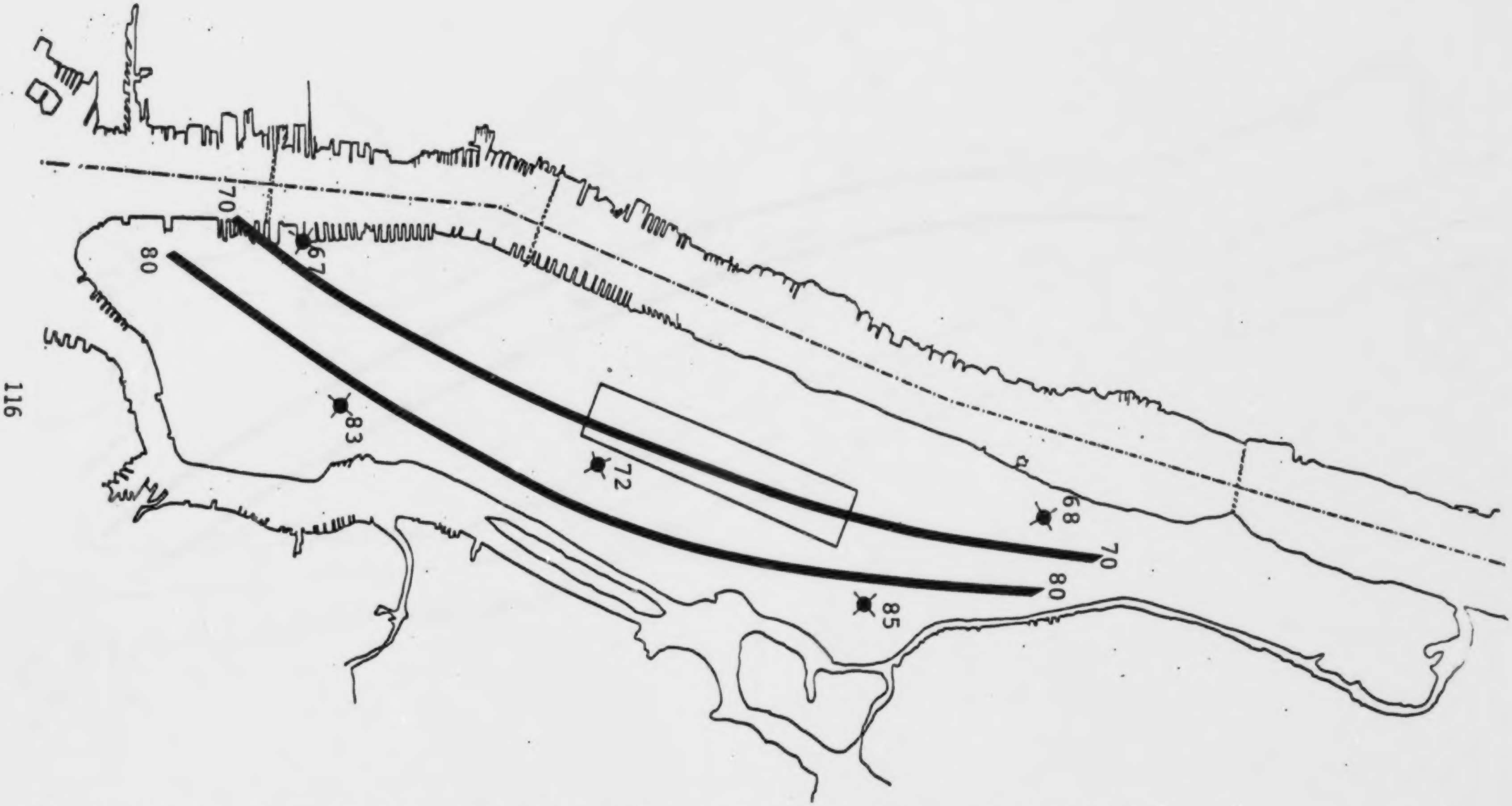
70
80
67
83
72
68
70
80
85

Figure 6-26. Year 1990 Projected TSP Distribution on Manhattan Island for Scenario Combination $T_1D_2E_1$.

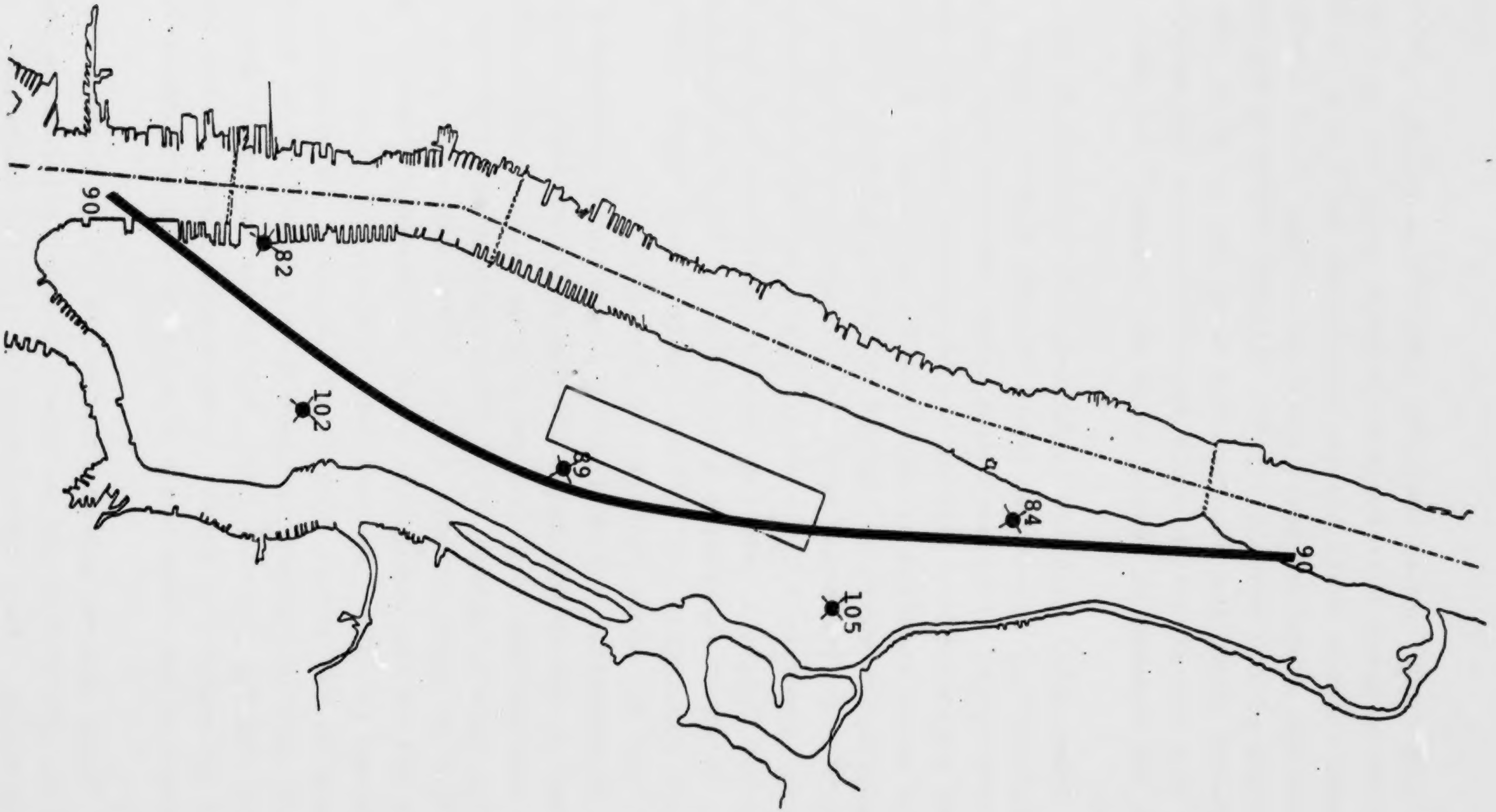
90
82
102
89
84
105
90

Figure 6-27. Year 2000 Projected TSP Distribution on Manhattan Island for Scenario Combination $T_1D_2E_1$.

long term (2000) under scenario combination $T_1D_1E_1$. This combination means that automobile usage would continue to increase, diesel would not be introduced, and the present low particulate emissions would continue. Under these conditions about 60% of the central Chicago citizens would be exposed to TSP levels above the standard and about 40% below in 1980. In year 2000 the situation would actually improve slightly, with about 50% exposed to levels above the standard and about 50% below.

Under other scenario conditions the exposure of the central Chicago population would be much higher. Under Scenario $T_1D_2E_1$ (increased auto usage combined with rapid diesel introduction) 100% of the population would be exposed to levels above standard by 1990 (see Figure 6-18). By year 2000 the population would be exposed to levels between 94 and $114\mu g/m^3$. On the other hand, if automobile usage were to stop growing (Scenario $T_2D_2E_1$) or if auto usage were to decline (Scenario $T_3D_2E_1$), then the exposure would not be quite so high, as shown in Figures 6-19 and 6-20. Nevertheless, almost all the population will be exposed to levels above standard by 1990, and far above standard by year 2000.

In Manhattan Island the TSP population is presently exposed to TSP levels below the national standard according to data from the New York City monitoring sites. Under Scenario $T_1D_1E_1$, this situation would remain essentially the same over the next 22 years (Figure 6-21). Under Scenario $T_1D_2E_1$ about 65% of the population would be exposed to levels above the NAAQS by 1990. By year 2000 the population would be exposed to TSP levels from 84 to $106\mu g/m^3$. Alternately, if the growth rate of automobile usage were reduced, as in Scenarios $T_2D_2E_1$ and $T_3D_2E_1$, then about 60% of the Manhattan population would be exposed to levels above standard by 1990 and the exposure in year 2000 would also be reduced (Figures 6-23 and 6-24).

These figures are another method for expressing the air quality levels that can be expected under alternative scenario combinations. They show, dramatically, the increased population exposure that can be expected if automobiles are rapidly dieselized. They also show the beneficial effects of switching from automobiles to buses and taxis, if dieselization should continue.

6.3 THE IMPACT OF SWITCHING TO MASS TRANSIT

One of the objectives of this study was to determine the impact of switching to mass transit, especially buses and taxis in the central city. This impact is inherent in the transportation scenarios and the different effects these scenarios have upon the ambient TSP levels at various monitoring sites in each of the three cities analyzed. For example, the effect of switching from automobiles to greater use of buses (and rail transport) is the difference between the projected TSP levels in T_1 and T_2 scenarios. This is not easy to visualize because so many factors were taken into account in the construction of these scenarios.

The effects of mass transit on TSP levels in each of these scenarios can be seen more clearly if the TSP contribution from each transportation mode is listed separately. To accomplish this, the alternate equation 8a in Appendix E was used in a separate computer run. The resulting tabulation is listed in Appendix H. Based on this data, one of the most centrally located monitoring sites from each of the three cities was chosen for exhibition in Figures 6-28 to 6-30. These figures present the TSP contribution from each of the four modes of vehicular transportation to a given monitoring site for three selected projection years. It should be noted that TSP contribution does not mean vehicle particulate emissions; rather, it means that portion of the ambient TSP level attributable to a given mode of transportation. In other words, if a mode of transportation were to magically vanish, the ambient TSP level would theoretically drop by the amount of TSP contribution from that mode of transportation.

Like the previous presentations, these figures show how the dieselization scenarios (D_1 versus D_2) dominate all other

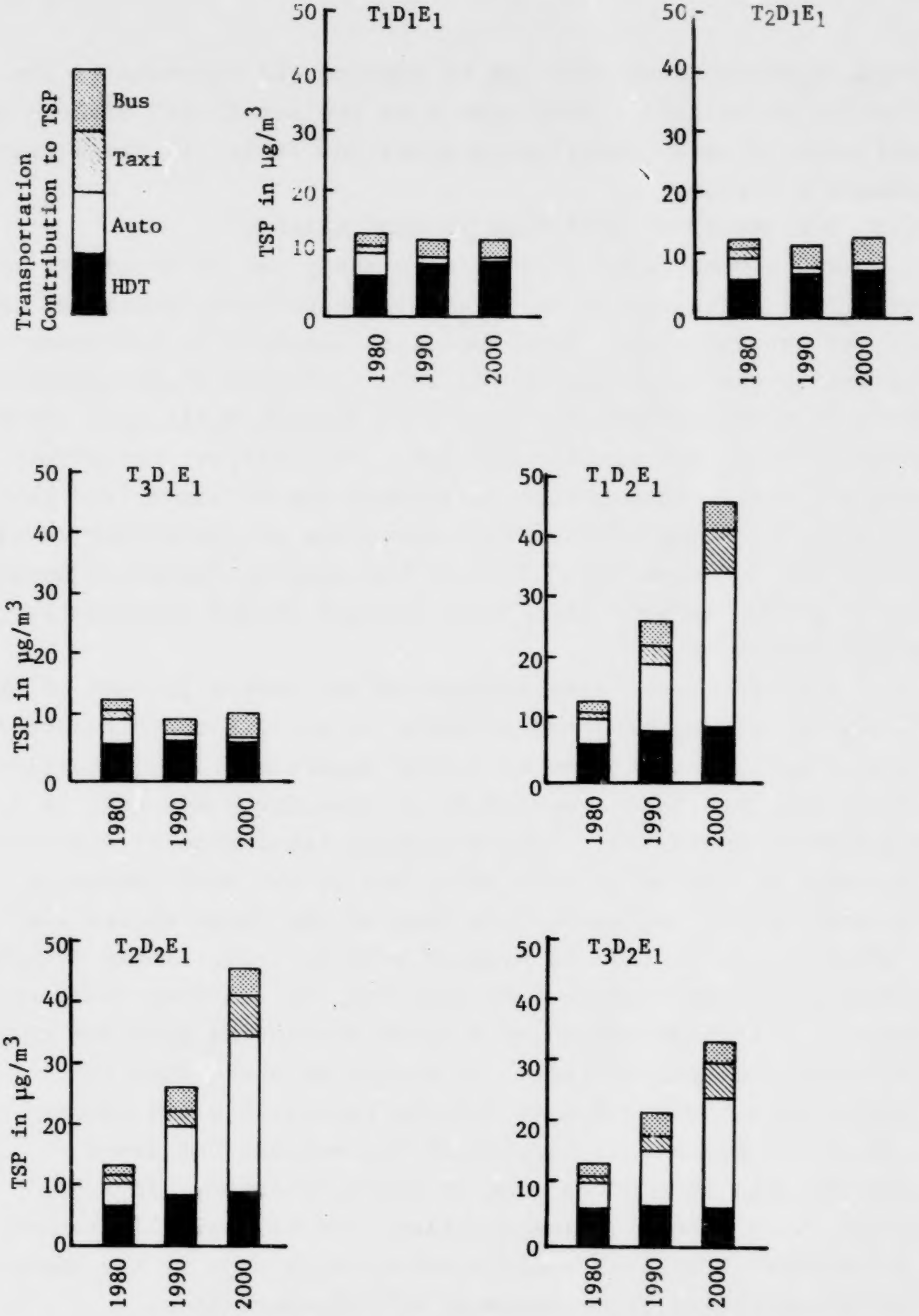

Figure 6-28. Projected TSP Contributions from Each Mode of Transportation to the Monitoring Site at 240 2nd Avenue, New York City.

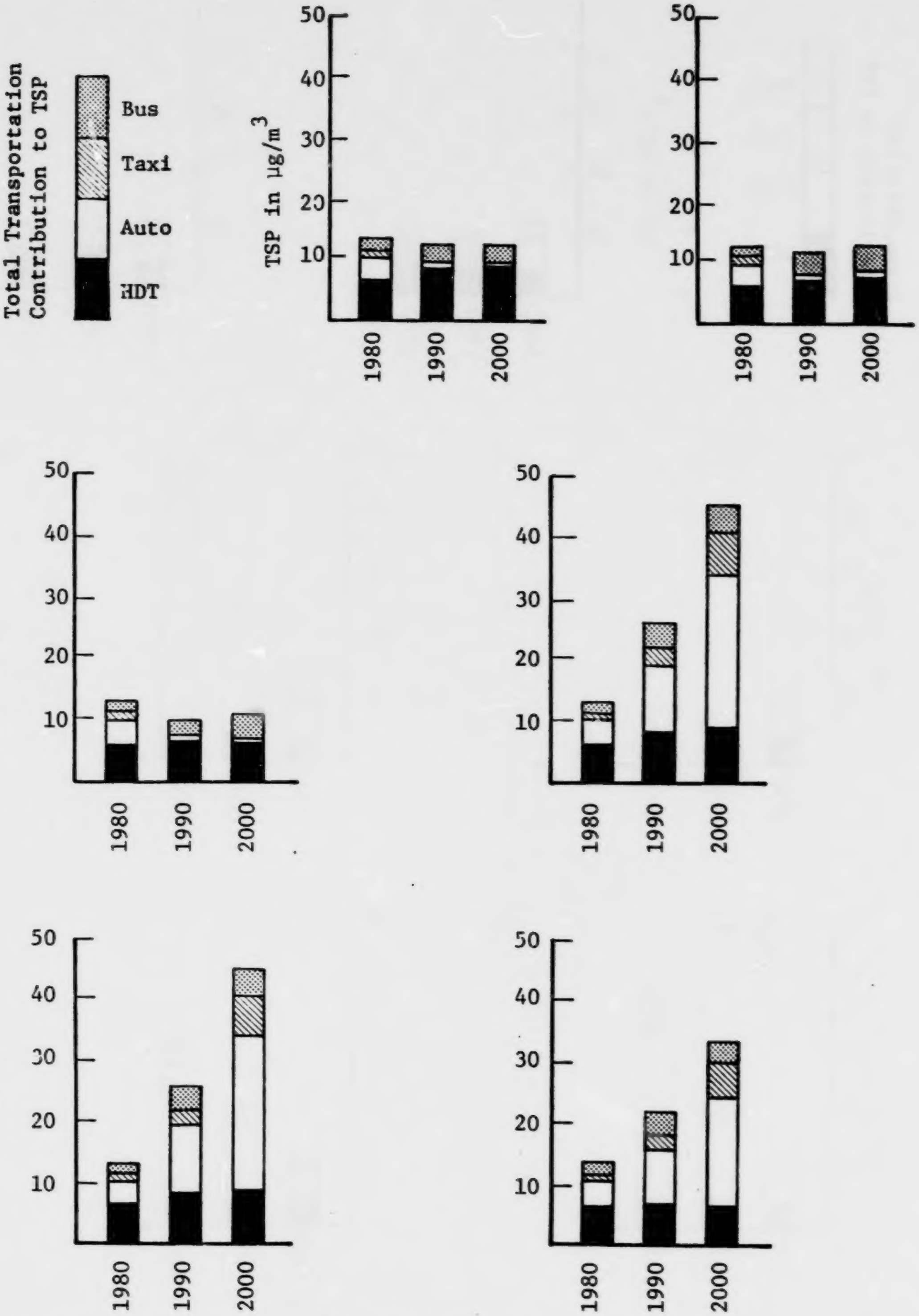

Figure 6-29. Projected TSP Contribution From Each Mode of Transportation to the Monitoring Site at 538 S. Clark St., Chicago

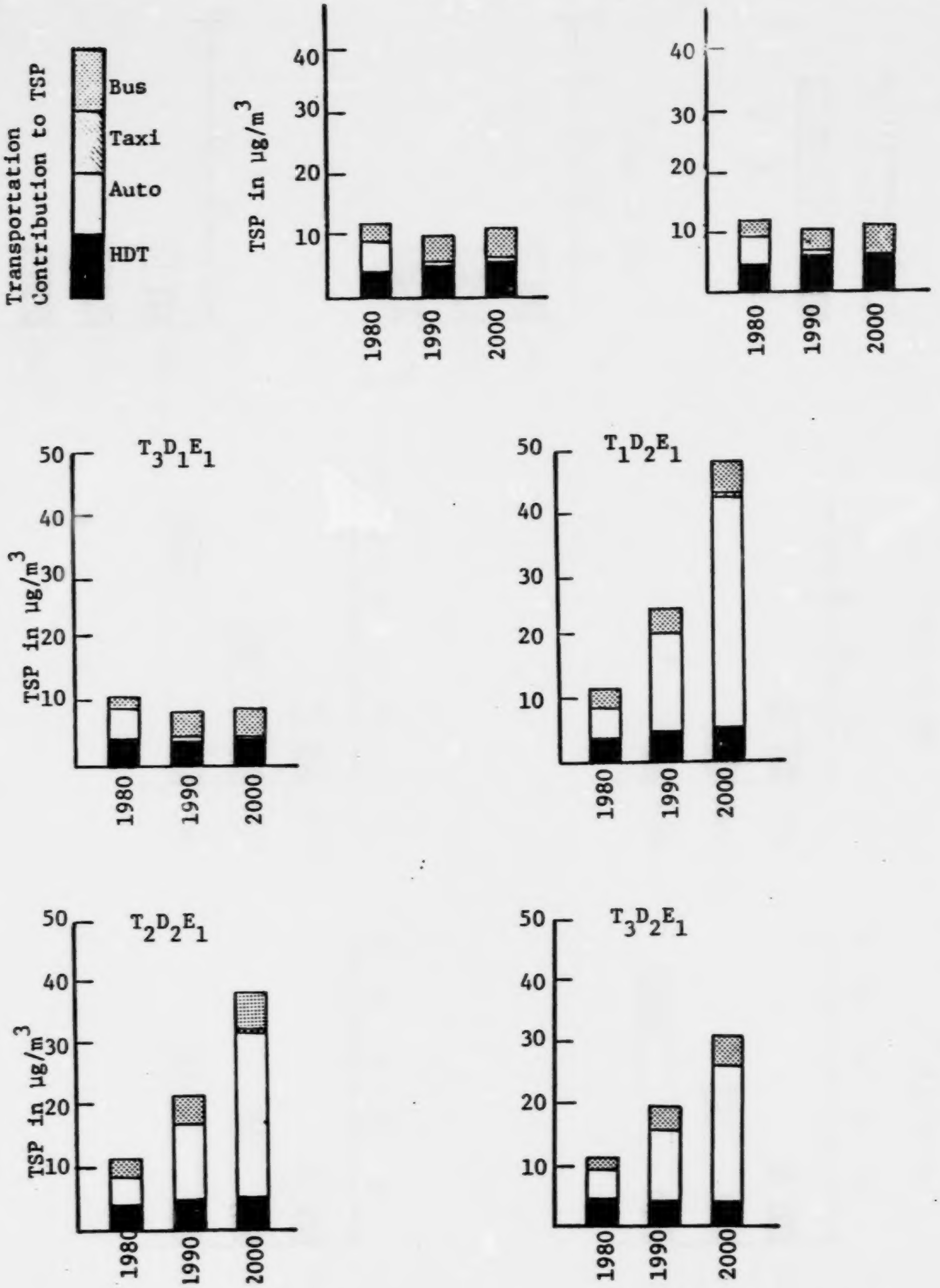

Figure 6-30. Projected TSP Contributions From Each Mode of Transportation to the Monitoring Site at 434 S. San Pedro St., Los Angeles.

effects. In D_1 scenarios, where the diesel engine remains an insignificant part of the automobile population, the automobile TSP contribution becomes minute and the taxi contribution essentially disappears. This is due to the continued introduction of catalyst-equipped vehicles with very low emission rates. In D_2 scenarios, where the diesel is introduced as the dominant automobile (and taxi) engine, the automobile TSP contribution rises dramatically, followed by the taxi contribution, which becomes very significant.

Careful scrutiny of these charts will reveal other, less obvious, impacts. For example, the TSP contributions of buses and heavy duty trucks increase in all scenario combinations. It will be recalled that the dieselization scenarios affect only automobiles and taxis, and that only a single projection was made for heavy duty trucks. Based on information from New York City, the diesel fraction of bus VMT was about the same for buses as for HDT's; therefore the same projection was applied to buses. Since the non-automobile vehicles are of special interest, it is worth examining this result more closely.

6.3.1 The Impact of Buses

In all scenarios, the TSP contribution from buses is projected to increase from 1978 to the year 2000. Based on the data from Appendix H, the bus contribution over this time period is tracked in Figure 6-31 for a monitoring site in downtown New York City. This steady increase has two causes. First, the percent of buses that contain diesel engines is expected to increase, and the number of bus miles that are diesel will also increase. The higher particulate emission rates from diesel buses compared to gasoline engines tend to increase the particulate emissions from the bus mode of transportation. Second, transportation planners expect bus VMT in cities to increase, whether automobile usage continues to increase (Scenario T_1), whether auto usage levels off and a modal shift occurs (Scenario T_2), or whether a modal shift occurs in combination with reduced transportation demand

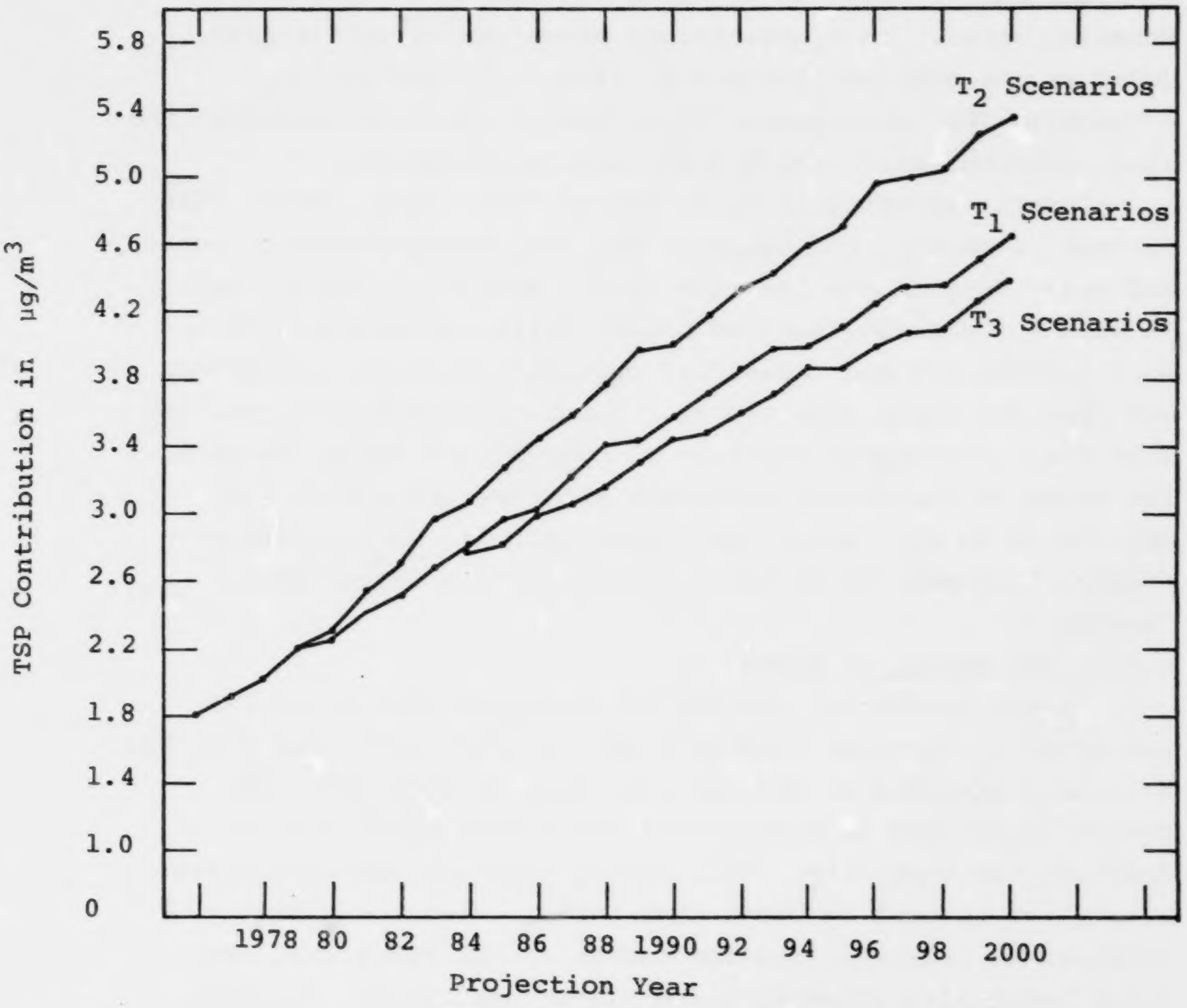

Figure 6-31. Projected TSP Contribution from the Bus Mode of Transportation to the Monitoring Site at 240 2nd Ave., New York City.

(Scenario T_3). However, the reason for the increase is different in all three cases.

In the T_1 scenario, bus VMT increases to meet the needs of the growing population of the elderly and the poor. Public agencies are able to increase their budgets for this purpose because of a continuing prosperous economy. In the T_2 scenario, bus VMT increases to meet the needs of a larger portion of the commuting population during a modal shift, in addition to meeting some of the increased needs of the elderly and the poor. Increased revenues may be obtained from rider fares as well as from public funds. The increased bus VMT pushes the TSP contribution somewhat higher for scenario T_2 than for scenario T_1. In scenario T_3, a less healthy economy tends to reduce the total demand for transportation services, including bus service. However, a modal shift from automobiles to bus commuting causes bus VMT mileage to increase almost as much in scenario T_3 as in scenario T_1. (See Figure 6-31.)

One of the questions that can arise is how a large reduction in the TSP contribution from automobiles can be achieved (e.g. the difference between scenarios $T_1D_2E_1$ and $T_3D_2E_1$), while at the same time there is only a modest increase in the TSP contribution from buses. In other words, since there is a decrease of 13.1 $\mu g/m^3$ in the TSP contribution from autos and taxies between scenarios T_1 and T_3 in the year 2000, why is there not a comparable increase in the bus contribution? (The comparable difference in the bus TSP contribution between scenarios T_1 and T_3 is only 0.3 $\mu g/m^3$.) The answer to this question lies in the nature of the bus vehicle and in the present commitment to improved bus service.

First of all, the bus is a large capacity vehicle which carries 40-50 persons at full load and many more people when the aisles are utilized. In other words, if bus service were expanded to accomodate a sudden change in the modal choice for commuting, one bus could theoretically accomodate 40-50 commuters. If the bus route was short enough to allow two trips during the rush hour, then perhaps 80-100 commuters could be accommodated. Therefore a very small increase in bus VMT can accommodate a very large reduction in the VMT of automobiles used for commuting.

Second, the modal shifts implied in scenarios T_2 and T_3 also involve the commuter rail services, which have such minor TSP emissions that they were deleted from this study. The portion of automobile VMT accommodated by electrically-operated subways will correlate with a zero increase in emissions in this study. (Point sources, such as power plants, were not included.) This will be true for New York and Chicago, but not for Los Angeles where there is no rail service.

Third, it was previously noted that there is a commitment to improve bus services in central cities for the poor and the elderly. This means that the VMT differences between the various scenarios are smaller for buses than they are for automobiles, since bus service is expanding in all three cases. Smaller VMT differences contribute to smaller differences between the TSP contributions from the bus mode of transportation in alternate scenarios.

The bus mode of transportation will contribute an increasingly significant amount of the ambient TSP levels in the future. In the T_2 scenarios the bus contribution to ambient TSP levels increases from about 1.8 $\mu g/m^3$ in 1976 to 5.3 $\mu g/m^3$ in the year 2000 at the monitoring site located at 240 2nd Avenue, New York City. At other monitoring sites in New York, the comparable year 2000 bus contribution ranges from 4.3 to 5.5 $\mu g/m^3$. At centrally located monitoring sites in downtown Chicago the comparable bus mode contribution to ambient TSP is 2.5 to 5.3 $\mu g/m^3$. In the central area of Los Angeles, the comparable TSP contribution rises from 2.1 $\mu g/m^3$ in 1976 to 5.5 $\mu g/m^3$ in the year 2000. In the non-dieselized-auto scenarios, the bus systems are second only to heavy duty trucks in contributions to ambient levels of TSP from transportation.

6.3.2 The Impact of Taxis

The impact of taxi transportation on the ambient TSP level

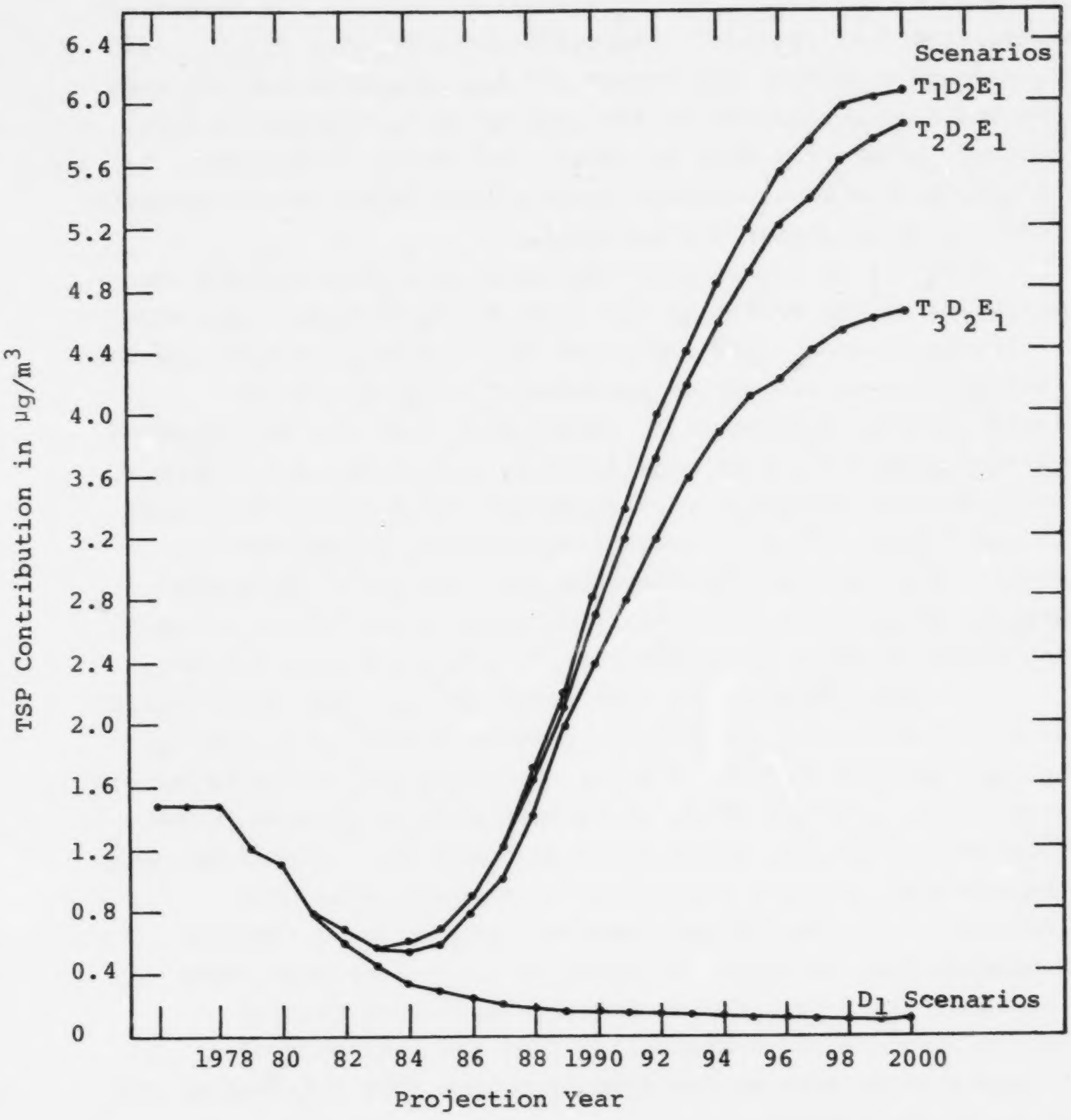

Figure 6-32. Projected TSP Contribution from the Taxi Mode of Transportation to the Monitoring Site at 240 2nd Ave., New York City.

is inherent in the results of scenario analysis. The differences between D_1 and D_2 scenarios includes the impact of dieselized taxi engines. The differences between T_1, T_2, and T_3 scenarios include the impact of taxi emissions and how they are modified by changes in the economy or by changes in modal choice. Unlike the case of buses, the amount of TSP contribution from taxis depends heavily upon which future scenario combination is chosen for analysis.

Figure 6-32 illustrates the vivid contrasts between the scenarios in the amount of TSP contributed from the taxi mode of transportation. The impact of taxi TSP emissions follow the same pattern as automobile emissions. If little or no dieselization is assumed (D_1 scenarios), then the VMT-weighted emissions become almost negligible by 1990, and the reduced emission rate accounts for the reduced TSP contribution shown in the figure. If full-scale dieselization is assumed (D_2 scenarios), then the TSP contribution from taxis increases dramatically. This increase is directly attributable to the increased emission rates associated with the diesel engine.

A modest reduction in auto usage and a modest modal shift, as reflected in the differences between scenarios T_1 and T_2, is not expected to cause a major change in the TSP contribution from taxis. The use of taxis is more closely related to the economy than to the modal choice of commuters. Therefore, when the scenario includes conditions of economic recession (scenario T_3), the TSP contribution from taxis is reduced substantially, as shown in Figure 6-32. Unless government intervenes in a forceful manner, the principal factors determining the TSP contribution from the taxi mode of transportation will be the type of engine used followed by the state of the economy.

6.4 CAVEATS

In this study, there were a number of conditions placed on the results. These conditions have been mentioned elsewhere in the report, but it suits the author to list these caveats as a part of the conclusions, as follows:

1. Projections of the future are highly conditional upon human factors that are too complex to be predictable. Therefore, one should realize that any one of the scenarios could be right or all of them could be wrong.

Unfortunately, we will have to wait 10-20 years to determine the accuracy of any one scenario.

2. This study was designed to isolate the effects of diesel emissions on TSP under various scenario assumptions. In order to perform this type of analysis, all non-transportation emissions must remain constant. For this reason the conditional projections in the report should not be confused with "predictions" of actual TSP levels to be expected. To make predictive forecasts, all sources of particulate emissions should be taken into account. The projections in this study should be used only to examine the effects of diesel policy alternatives on ambient TSP levels.

3. The relationship between emissions and air quality at each monitoring site was based on trace element studies calibrated at similar, but not the same, locations. More accuracy would be possible if the local air monitoring stations were identical to the research stations.

4. The trace element technique is generally an improvement over regional inventory methods. However, Pace[1] has developed a technique that allows TSP levels to be statistically correlated with factors identified through a microinventory of the area immediately surrounding a given monitoring site. This statistical model has not been calibrated for monitoring sites in these three cities, but no doubt this new method will be very useful in future studies of this type. Itis possible that an inventory method would show somewhat higher diesel impacts on TSP.

5. The present report is based on currently available emission factors (E_1) which have greatly affected the outcome of the analysis. The method used in this report can easily be applied to other emission factors as further research shows them to be applicable.

6. Data from 1975 to 1977 were used to develop a standard meteorological year, and all monitoring data were normalized to this standard year. As meteorological conditions vary unpredictably from these standard conditions, so would the projections of TSP levels. This is another reason for using these projections only for analyzing policy alternatives and not for forecasting.

7. This study was directed to the problem of the impact of diesel particulates. It should not be forgotten that diesel engines are likely to benefit air quality by the reduced emissions of gaseous pollutants, such as carbon monoxide. The full range of costs and benefits are not treated in this report.

In summary, the results of this study show that switching from automobiles to alternative modes of transportation, such as taxis or buses, will have only a minor impact on ambient TSP levels as long as current types of emission controls are used. However, if the automobile population is converted to diesel, there will be substantial increases in the TSP levels experienced in the large cities after 1985. In this case, the modal choice of the citizens will determine the extent of the adverse impact.

6.5 REFERENCE

1. Pace, Thompson G., "An Empirical Approach for Relating Particulate Microinventory Emissions Data, Monitoring Siting Characteristics and Annual TSP Concentrations", Air Management Technology Branch, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, January 1979 (unpublished draft).

APPENDIX A. PROJECTIONS OF MODAL CHOICE ACCORDING TO THREE TRANSPORTATION SCENARIOS

TABLE A-1. PROJECTION YEAR MODAL CHOCIES FOR T_1 SCENARIOS IN NEW YORK CITY

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT^a	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.32	.019	1.374	.020	1.428	.021	1.482	.022	1.536	.022
TAXI	12.64	.183	12.725	.185	12.809	.186	12.894	.187	12.979	.188
AUTO	50.77	.737	51.130	.742	51.491	.747	51.851	.752	52.212	.758
HDT^b	4.18	.061	4.210	.061	4.239	.062	4.269	.062	4.299	.062
TOTAL	68.91	1.000	69.439	1.008	69.967	1.016	70.496	1.023	71.026	1.026

MODE	1981		1982		1983		1984		1985	
	n-VMT^a	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.591	.023	1.645	.024	1.699	.025	1.753	.025	1.807	.026
TAXI	13.063	.190	13.148	.191	13.233	.192	13.318	.193	13.402	.194
AUTO	52.572	.763	52.933	.768	53.293	.773	53.654	.779	54.014	.784
HDT^b	4.328	.063	4.358	.063	4.388	.064	4.417	.064	4.447	.065
TOTAL	71.497	1.039	72.084	1.046	72.613	1.054	73.142	1.061	73.670	1.069

MODE	1986		1987		1988		1989		1990	
	n-VMT^a	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.861	.027	1.915	.028	1.969	.029	2.024	.029	2.078	.030
TAXI	13.487	.196	13.572	.197	13.656	.198	13.741	.199	13.826	.201
AUTO	54.375	.789	54.735	.794	55.096	.800	55.456	.805	55.817	.810
HDT^b	4.77	.065	4.506	.065	4.536	.066	4.566	.066	4.595	.067
TOTAL	74.200	1.077	74.728	1.084	75.257	1.093	75.787	1.099	76.316	1.108

TABLE A-1. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.132	.031	2.186	.032	2.240	.033	2.294	.033	2.348	.034
TAXI	13.910	.202	13.995	.203	14.080	.204	14.164	.206	14.249	.207
AUTO	56.177	.815	56.537	.820	56.898	.826	57.258	.831	57.619	.836
HDT[b]	4.625	.067	4.655	.068	4.685	.068	4.714	.068	4.744	.069
TOTAL	76.844	1.115	77.373	1.123	77.903	1.131	78.430	1.138	78.960	1.146

MODE	1996		1997		1998		1999		2000	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.402	.035	2.457	.036	2.511	.036	2.565	.037	2.619	.038
TAXI	14.334	.208	14.418	.209	14.503	.210	14.588	.212	14.673	.213
AUTO	57.979	.841	58.340	.847	58.700	.852	59.061	.857	59.421	.862
HDT[b]	4.774	.069	4.803	.070	4.833	.070	4.863	.071	4.892	.071
TOTAL	79.489	1.153	80.018	1.162	80.547	1.168	81.077	1.177	81.605	1.184

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-2. PROJECTION YEAR MODAL CHOCIES FOR T_2 SCENARIOS IN NEW YORK CITY

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.32	.019	1.393	.020	1.465	.021	1.538	.022	1.610	.023
TAXI	12.64	.183	12.682	.184	12.723	.185	12.765	.185	12.807	.186
AUTO	50.77	.737	50.77	.737	50.77	.737	50.77	.737	50.77	.737
HDT[b]	4.18	.061	4.194	.061	4.208	.061	4.221	.061	4.235	.061
TOTAL	68.91	1.000	69.039	1.002	69.166	1.004	69.294	1.005	69.422	1.007

MODE	1981		1982		1983		1984		1985	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.683	.024	1.756	.025	1.828	.027	1.901	.028	1.973	.029
TAXI	12.849	.186	12.890	.187	12.932	.188	12.974	.188	13.015	.189
AUTO	50.77	.737	50.77	.737	50.77	.737	50.77	.737	50.77	.737
HDT[b]	4.249	.062	4.263	.062	4.277	.062	4.290	.062	4.304	.062
TOTAL	69.551	1.009	69.679	1.011	69.807	1.014	69.935	1.015	70.062	1.019

MODE	1986		1987		1988		1989		1990	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.046	.030	2.119	.031	2.191	.032	2.264	.033	2.336	.034
TAXI	13.057	.189	13.099	.190	13.141	.191	13.182	.192	13.266	.193
AUTO	50.77	.737	50.77	.737	50.77	.737	50.77	.737	50.77	.737
HDT[b]	4.318	.063	4.332	.063	4.346	.063	4.359	.063	4.373	.063
TOTAL										

TABLE A-2. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.409	.035	2.482	.036	2.554	.037	2.627	.038	2.699	.039
TAXI	13.266	.193	13.307	.193	13.349	.194	13.391	.194	13.433	.195
AUTO	50.77	.737	50.77	.737	50.77	.737	50.77	.737	50.77	.737
HDT[b]	4.387	.064	4.401	.064	4.414	.064	4.428	.064	4.442	.064
TOTAL	70.832	1.029	70.960	1.030	71.087	1.032	71.216	1.033	71.344	1.036

MODE	1996		1997		1998		1999		2000	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.772	.040	2.845	.041	2.917	.042	2.990	.043	3.062	.044
TAXI	13.474	.196	13.516	.196	13.558	.197	13.599	.197	13.641	.198
AUTO	50.77	.737	50.77	.737	50.77	.737	50.77	.737	50.77	.737
HDT[b]	4.456	.065	4.470	.065	4.483	.065	4.497	.065	4.511	.065
TOTAL	71.472	1.038	71.601	1.039	71.728	1.041	71.856	1.042	71.984	1.044

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-3. PROJECTION YEAR MODAL CHCICES FOR T_3 SCENARIOS IN NEW YORK CITY

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.32	.019	1.368	.020	1.415	.021	1.463	.021	1.510	.022
TAXI	12.64	.183	12.564	.182	12.488	.181	12.412	.180	12.337	.179
AUTO	50.77	.737	50.435	.732	50.100	.727	49.765	.722	49.430	.717
HDT[b]	4.18	.061	4.152	.060	4.125	.060	4.097	.059	4.070	.059
TOTAL	68.91	1.000	68.519	.994	68.128	.989	67.737	.982	67.347	.977

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.558	.023	1.605	.023	1.653	.024	1.700	.025	1.749	.025
TAXI	12.261	.178	12.185	.177	12.109	.176	12.033	.175	11.957	.174
AUTO	49.095	.712	48.760	.708	48.424	.703	48.089	.689	47.754	.693
HDT	4.042	.059	4.014	.058	3.987	.058	3.959	.057	3.930	.057
TOTAL	66.956	.972	66.564	.966	66.173	.961	65.781	.955	65.391	.949

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.795	.026	1.843	.027	1.890	.027	1.938	.028	1.985	.029
TAXI	11.882	.172	11.806	.171	11.730	.170	11.654	.169	11.578	.168
AUTO	47.419	.688	47.084	.683	46.749	.678	46.414	.674	46.079	.669
HDT	3.904	.057	3.877	.056	3.849	.056	3.821	.055	3.794	.055
TOTAL	65.000	.943	64.610	.937	64.218	.931	63.827	.926	63.436	.921

TABLE A-3. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.033	.029	2.080	.030	2.128	.031	2.175	.032	2.223	.032
TAXI	11.502	.167	11.427	.166	11.351	.165	11.275	.164	11.199	.163
AUTO	45.744	.664	45.409	.659	45.074	.654	44.739	.649	44.403	.644
HDT[b]	3.766	.055	3.739	.054	3.711	.054	3.683	.053	3.656	.053
TOTAL	63.045	.915	62.655	.909	62.264	.904	61.872	.898	61.481	.892

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	2.270	.033	2.318	.034	2.365	.034	2.413	.035	2.460	.036
TAXI	11.123	.161	11.047	.160	10.972	.159	10.896	.158	10.820	.157
AUTO	44.068	.640	43.733	.635	43.398	.630	43.063	.625	42.728	.620
HDT	3.628	.053	3.601	.052	3.573	.052	3.545	.051	3.518	.051
TOTAL	61.089	.887	60.699	.881	60.308	.875	59.917	.869	59.526	.864

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-4. PROJECTION YEAR MODAL CHOICES FOR T_1 SCENARIOS IN CHICAGO

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	6.1	.012	6.253	.012	6.405	.013	6.558	.013	6.710	.013
TAXI	148.0	.293	148.577	.294	149.154	.295	149.732	.296	150.309	.297
AUTO	334.0	.661	335.503	.664	337.006	.667	338.509	.670	340.012	.672
HDT[b]	17.5	.034	17.579	.035	17.658	.035	17.736	.035	17.815	.035
TOTAL	505.6	1.000	507.912	1.005	510.223	1.010	512.535	1.014	514.846	1.017

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	6.863	.014	7.015	.014	7.168	.014	7.320	.014	7.473	.015
TAXI	150.886	.298	151.463	.300	152.040	.301	152.618	.302	153.195	.303
AUTO	341.515	.675	343.018	.678	344.521	.681	346.024	.684	346.527	.687
HDT	17.894	.035	17.973	.036	18.051	.036	18.130	.036	18.209	.036
TOTAL	517.158	1.022	519.469	1.028	521.780	1.032	524.092	1.036	526.404	1.041

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	7.625	.015	7.778	.015	7.930	.016	8.083	.016	8.235	.016
TAXI	153.772	.304	154.349	.305	154.926	.306	155.504	.308	156.081	.309
AUTO	349.030	.690	350.533	.693	352.036	.696	353.539	.699	355.042	.702
HDT	18.288	.036	18.366	.036	18.445	.036	18.524	.037	18.603	.037
TOTAL	528.715	1.045	531.026	1.049	533.337	1.054	535.650	1.060	537.961	1.064

TABLE A-4. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	8.388	.017	8.540	.017	8.693	.017	8.845	.017	8.998	.018
TAXI	156.658	.310	157.235	.311	157.812	.312	158.390	.313	158.967	.314
AUTO	356.545	.705	358.048	.708	359.551	.711	361.054	.714	362.557	.717
HDT[b]	18.681	.037	18.760	.037	18.839	.037	18.918	.037	18.996	.038
TOTAL	540.272	1.069	542.583	1.073	544.895	1.077	547.207	1.081	549.518	1.087

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	9.150	.018	9.303	.018	9.455	.019	9.608	.019	9.760	.019
TAXI	159.544	.316	160.121	.317	160.698	.318	161.276	.319	161.853	.320
AUTO	364.060	.720	365.563	.723	367.066	.726	368.569	.729	370.072	.732
HDT	19.075	.038	19.154	.038	19.233	.038	19.311	.038	19.390	.038
TOTAL	551.829	1.092	554.141	1.096	556.452	1.101	558.764	1.105	561.075	1.109

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-5. PROJECTION YEAR MODAL CHOICES FOR T_2 SCENARIOS IN CHICAGO

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	6.1	.012	6.301	.012	6.503	.013	6.704	.013	6.905	.014
TAXI	148.0	.293	147.701	.292	147.408	.292	147.112	.291	146.816	.290
AUTO	334.0	.661	334.0	.661	334.0	.661	334.0	.661	334.0	.661
HDT[b]	17.5	.034	17.465	.035	17.430	.034	17.395	.034	17.360	.034
TOTAL	505.6	1.000	505.470	1.000	505.341	1.000	505.211	.999	505.081	.999

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	7.107	.014	7.308	.014	7.509	.015	7.710	.015	7.912	.016
TAXI	146.520	.290	146.224	.289	145.928	.289	145.632	.288	145.336	.287
AUTO	334.0	.661	334.0	.661	334.0	.661	334.0	.661	334.0	.661
HDT	17.325	.034	17.290	.034	17.255	.034	17.220	.034	17.185	.034
TOTAL	504.952	.999	504.822	.999	504.692	.999	504.562	.998	504.433	.998

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	8.113	.016	8.314	.016	8.516	.017	8.717	.017	8.918	.018
TAXI	145.040	.287	144.744	.286	144.448	.286	144.152	.285	143.856	.285
AUTO	334.0	.661	334.0	.661	334.0	.661	334.0	.661	334.0	.661
HDT	17.150	.034	17.115	.034	17.080	.034	17.045	.034	17.010	.034
TOTAL	504.303	.998	504.173	.997	504.044	.998	503.914	.997	503.784	.998

TABLE A-5. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	9.120	.018	9.321	.018	9.522	.019	9.723	.019	9.925	.020
TAXI	143.560	.284	143.264	.283	142.968	.283	142.672	.282	142.376	.282
AUTO	334.0	.661	334.0	.661	334.0	.661	334.0	.661	334.0	.661
HDT[b]	16.975	.034	16.940	.034	16.905	.033	16.870	.033	16.835	.033
TOTAL	503.655	.997	503.525	.996	503.395	.996	503.265	.995	503.136	.996

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	10.126	.020	10.327	.020	10.529	.021	10.730	.021	10.931	.022
TAXI	142.080	.281	141.784	.280	141.488	.280	141.192	.279	140.896	.279
AUTO	334.0	.661	334.0	.661	334.0	.661	334.0	.661	334.0	.661
HDT	16.800	.033	16.765	.033	16.730	.033	16.695	.033	16.660	.033
TOTAL										

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-6. PROJECTION YEAR MODAL CHOICES FOR T_3 SCENARIOS IN CHICAGO

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	6.1	.012	6.289	.012	6.478	.013	6.667	.013	6.856	.014
TAXI	148.0	.293	146.638	.290	145.277	.287	143.915	.285	142.554	.282
AUTO	334.0	.661	330.727	.654	327.454	.648	324.180	.641	320.907	.635
HDT[b]	17.5	.034	17.329	.034	17.157	.034	16.986	.034	16.814	.033
TOTAL	505.6	1.000	500.983	.990	496.366	.982	491.748	.973	487.131	.964

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	7.046	.014	7.235	.014	7.424	.015	7.613	.015	7.802	.015
TAXI	141.192	.279	139.830	.277	138.469	.274	137.107	.271	135.746	.268
AUTO	317.634	.628	314.361	.622	311.088	.615	307.814	.609	304.541	.602
HDT	16.643	.033	16.471	.033	16.300	.032	16.128	.032	15.957	.032
TOTAL	482.515	.954	477.897	.946	473.281	.936	468.662	.927	464.046	.917

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	7.991	.016	8.180	.016	8.369	.017	8.558	.017	8.747	.017
TAXI	134.384	.266	133.022	.263	131.661	.260	130.299	.258	128.938	.255
AUTO	301.268	.596	297.995	.589	294.722	.583	291.448	.576	288.175	.570
HDT	15.785	.031	15.614	.031	15.442	.031	15.271	.030	15.099	.030
TOTAL	459.428	.909	454.811	.899	450.194	.891	445.576	.881	440.959	.872

TABLE A-6. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	8.937	.018	9.126	.018	9.315	.018	9.504	.019	9.693	.019
TAXI	127.576	.252	126.214	.250	124.853	.247	123.491	.244	122.130	.242
AUTO	284.902	.563	281.629	.557	278.356	.551	275.082	.544	271.809	.538
HDT[b]	14.928	.030	14.756	.029	14.585	.029	14.413	.029	14.242	.028
TOTAL	436.343	.863	431.725	.854	427.109	.845	422.490	.836	417.874	.827

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	9.882	.020	10.071	.020	10.260	.020	10.449	.021	10.449	.021
TAXI	120.768	.239	119.406	.236	118.045	.233	116.683	.231	115.322	.228
AUTO	268.536	.531	265.263	.525	261.990	.518	258.716	.512	255.443	.505
HDT	14.070	.028	13.899	.027	13.727	.027	13.556	.027	13.384	.026
TOTAL	413.256	.818	408.639	.808	404.022	.798	399.404	.791	394.598	.780

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-7. PROJECTION YEAR MODAL CHOICES FOR T_1 SCENARIOS IN LOS ANGELES

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.78	.022	.806	.023	.831	.024	.857	.024	.883	.025
TAXI	.36	.010	.362	.010	.363	.010	.365	.010	.366	.010
AUTO	32.49	.926	33.026	.941	33.562	.956	34.098	.972	34.634	.987
HDT[b]	1.46	.042	1.467	.042	1.474	.042	1.481	.042	1.489	.042
TOTAL	35.09	1.000	35.661	1.016	36.230	1.032	36.801	1.048	37.372	1.064

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.909	.026	.934	.027	.960	.027	.986	.028	1.012	.029
TAXI	.368	.010	.369	.011	.371	.011	.372	.011	.374	.011
AUTO	35.170	1.002	35.707	1.018	36.243	1.033	36.779	1.048	37.315	1.063
HDT	1.496	.043	1.503	.043	1.510	.043	1.517	.043	1.524	.043
TOTAL	37.943	1.018	38.513	1.099	39.084	1.114	39.654	1.130	40.225	1.146

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.037	.030	1.063	.030	1.089	.031	1.115	.032	1.140	.032
TAXI	.375	.011	.377	.011	.379	.011	.380	.011	.382	.011
AUTO	37.851	1.079	38.387	1.094	38.923	1.109	39.459	1.125	39.995	1.140
HDT	1.532	.044	1.539	.044	1.546	.044	1.553	.044	1.560	.044
TOTAL	40.795	1.164	41.366	1.179	41.937	1.195	42.507	1.212	43.077	1.227

TABLE A-7. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.166	.033	1.192	.034	1.218	.035	1.243	.035	1.269	.036
TAXI	.383	.011	.385	.011	.386	.011	.388	.011	.389	.011
AUTO	40.531	1.155	41.067	1.170	41.603	1.186	42.140	1.201	42.676	1.216
HDT[b]	1.567	.045	1.574	.045	1.582	.045	1.589	.045	1.596	.045
TOTAL	43.647	1.244	44.218	1.260	44.789	1.277	45.360	1.292	45.930	1.308

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.295	.037	1.321	.038	1.346	.038	1.372	.039	1.398	.040
TAXI	.391	.011	.393	.011	.394	.011	.396	.011	.397	.011
AUTO	43.212	1.231	43.748	1.247	44.284	1.262	44.820	1.277	45.356	1.293
HDT	1.603	.046	1.610	.046	1.617	.046	1.625	.046	1.632	.041
TOTAL	46.501	1.325	47.072	1.342	47.641	1.357	48.213	1.373	48.783	1.391

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-8. PROJECTION YEAR MODAL CHOICES FOR T_2 SCENARIOS IN LOS ANGELES

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.78	.022	.814	.023	.849	.024	.883	.025	.917	.026
TAXI	.36	.010	.361	.010	.362	.010	.362	.010	.363	.010
AUTO	32.49	.926	32.49	.926	32.49	.926	32.49	.926	32.49	.926
HDT[b]	.146	.042	1.463	.042	1.466	.042	1.469	.042	1.472	.042
TOTAL	35.09	1.000	35.128	1.001	35.167	1.002	35.204	1.003	35.242	1.004

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.952	.027	.986	.028	1.020	.029	1.055	.030	1.089	.031
TAXI	.364	.010	.365	.010	.365	.010	.366	.010	.367	.010
AUTO	32.49	.926	32.49	.926	32.49	.926	32.49	.926	32.49	.926
HDT	1.475	.042	1.478	.042	1.481	.042	1.485	.042	1.488	.042
TOTAL	35.281	1.005	35.319	1.006	35.356	1.007	35.396	1.008	35.434	1.009

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.123	.032	1.158	.033	1.192	.034	1.226	.035	1.260	.036
TAXI	.368	.010	.368	.010	.369	.011	.370	.011	.371	.011
AUTO	32.49	.926	32.49	.926	32.49	.926	32.49	.926	32.49	.926
HDT	1.491	.042	1.494	.043	1.497	.043	1.500	.043	1.503	.043
TOTAL	35.472	1.010	35.510	1.012	35.548	1.014	35.586	1.015	35.624	1.016

TABLE A-8. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.295	.037	1.329	.038	1.363	.039	1.398	.040	1.432	.041
TAXI	.371	.011	.372	.011	.373	.011	.374	.011	.374	.011
AUTO	32.49	.926	32.49	.926	32.49	.926	32.49	.926	32.49	.926
HDT[b]	1.506	.043	1.509	.043	1.512	.043	1.515	.043	1.518	.043
TOTAL	35.662	1.017	35.700	1.018	35.738	1.019	35.777	1.020	35.814	1.021

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.466	.042	1.501	.043	1.535	.044	1.569	.045	1.604	.046
TAXI	.375	.011	.376	.011	.377	.011	.377	.011	.378	.011
AUTO	32.49	.926	32.49	.926	32.49	.926	32.49	.926	32.49	.926
HDT	1.521	.043	1.524	.043	1.527	.044	1.531	.044	1.534	.044
TOTAL	35.852	1.022	35.891	1.023	35.929	1.025	35.967	1.026	36.006	1.027

[a] n-VMT = normalized vehicle miles traveled.

[b] HDT = heavy duty truck.

TABLE A-9. PROJECTION YEAR MODAL CHOICES FOR T_3 SCENARIOS IN LOS ANGELES

MODE	1976 Base		1977		1978		1979		1980	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.78	.022	.808	.023	.836	.024	.864	.025	.892	.025
TAXI	.36	.010	.357	.010	.355	.010	.352	.010	.350	.010
AUTO	32.49	.926	32.243	.919	31.996	.912	31.749	.905	31.502	.898
HDT[b]	1.46	.042	1.449	.041	1.438	.041	1.427	.041	1.416	.040
TOTAL	35.09	1.000	34.857	.993	34.625	.987	34.392	.981	34.160	.967

MODE	1981		1982		1983		1984		1985	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	.920	.026	.948	.027	.977	.028	1.005	.029	1.033	.029
TAXI	.347	.010	.345	.010	.342	.010	.340	.010	.337	.010
AUTO	31.255	.891	31.008	.884	30.726	.877	30.515	.870	30.268	.863
HDT	1.405	.040	1.393	.040	1.382	.039	1.371	.039	1.360	.039
TOTAL	33.927	.967	33.694	.961	33.462	.954	33.231	.948	32.998	.941

MODE	1986		1987		1988		1989		1990	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.061	.030	1.089	.031	1.117	.032	1.145	.033	1.173	.033
TAXI	.335	.010	.332	.009	.330	.009	.327	.009	.325	.009
AUTO	30.021	.856	29.774	.848	29.527	.841	29.280	.834	29.033	.827
HDT	1.349	.038	1.338	.038	1.327	.038	1.316	.037	1.305	.037
TOTAL	32.766	.934	32.533	.926	32.301	.920	32.068	.913	31.836	.906

TABLE A-9. (CONTINUED)

MODE	1991		1992		1993		1994		1995	
	n-VMT[a]	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.201	.034	1.229	.035	1.257	.036	1.285	.037	1.314	.037
TAXI	.322	.009	.320	.009	.317	.009	.315	.009	.312	.009
AUTO	28.786	.820	28.539	.813	28.292	.806	28.045	.799	27.798	.792
HDT[b]	1.294	.037	1.282	.037	1.271	.036	1.260	.036	1.249	.036
TOTAL	31.603	.900	31.370	.894	31.137	.887	30.905	.881	30.673	.874

MODE	1996		1997		1998		1999		2000	
	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION	n-VMT	FRACTION
BUS	1.342	.038	1.370	.039	1.398	.040	1.426	.041	1.454	.041
TAXI	.310	.009	.307	.009	.305	.009	.302	.009	.300	.009
AUTO	27.552	.785	27.305	.778	27.058	.771	26.811	.764	26.564	.757
HDT	1.238	.035	1.227	.035	1.216	.035	1.205	.034	1.194	.034
TOTAL	30.442	.867	30.209	.861	29.977	.855	29.744	.848	29.512	.841

[a] n-VMT = nromalized vehicle miles traveled.

[b] HDT = heavy duty truck.

APPENDIX B: DERIVATION OF EQUATIONS FOR α AND β PARAMETERS IN THE CUMULATIVE LOGISTIC DISTRIBUTION FORMULA

APPENDIX B

The following step-by-step derivation was contributed by Ted Johnson, PEDCo Environmental, Inc., Durham, N.C. The formula for the cumulative logistic distribution is as follows (see Chapter 3):

(1) $$F(x) = \left\{1 + \exp\left[-\frac{x - \alpha}{\beta}\right]\right\}^{-1}$$

where

x = projection year of interest: 78, 79, 80 etc.

F(x) = fraction of new vehicle sales that are diesel.

α and β = scaler factors determining the shape of the curve.

(2) $$1 + \exp\left(-\frac{x - \alpha}{\beta}\right) = \frac{1}{F(x)}$$

(3) $$\exp\left(-\frac{x - \alpha}{\beta}\right) = \frac{1}{F(x)} - 1$$

(4) $$-\frac{x - \alpha}{\beta} = \ln\left(\frac{1}{F(x)} - 1\right)$$

(5) $$\frac{x - \alpha}{\beta} = -\ln\left(\frac{1}{F(x)} - 1\right)$$

(6) $$\frac{x - \alpha}{\beta} = -\ln\left(\frac{1 - F(x)}{F(x)}\right)$$

(7) $$\frac{x - \alpha}{\beta} = \ln\left(\frac{F(x)}{1 - F(x)}\right)$$

(8) $$x = \alpha + \beta\ln\left(\frac{F(x)}{1 - F(x)}\right)$$

This form of the equation is used to estimate the year in which a given fraction of automotive sales will be diesel. It also isolates α and β in a convenient form.

Let us now assume that two points on the curve are known: $(x_1, F(x_1))$ and $(x_2, F(x_2))$. We then have:

$$(9) \qquad x_1 = \alpha + \beta \ln \left(\frac{F(x_1)}{1 - F(x_1)} \right) \qquad \text{from Equation 8}$$

$$(10) \qquad x_2 = \alpha + \beta \ln \left(\frac{F(x_2)}{1 - F(x_2)} \right) \qquad \text{from Equation 8}$$

$$(11) \quad x_1 - x_2 = \beta \left\{ \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\}$$

$$(12) \quad \beta = (x_1 - x_2) \left\{ \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\}^{-1}$$

Equation (12) can be used to determine β, given two points on the curve. Now let us derive an equation for α.

$$(13) \quad x_1 = \alpha + (x_1 - x_2) \left\{ \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\}^{-1} \ln \left\{ \frac{F(x_1)}{1 - F(x_1)} \right\}$$

This is from Equation 9, substituting β from Equation 12.

$$(14) \quad \alpha = x_1 - (x_1 - x_2) \left\{ \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\}^{-1} \ln \left\{ \frac{F(x_1)}{1 - F(x_1)} \right\}$$

$$(15) \quad \alpha = \left\{ x_2 \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - x_1 \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\} \left\{ \ln \left[\frac{F(x_1)}{1 - F(x_1)} \right] - \ln \left[\frac{F(x_2)}{1 - F(x_2)} \right] \right\}^{-1}$$

Equation (15) can be used to determine α given two points on the curve.

APPENDIX C. TABLES OF PROJECTED DIESEL SALES AND DIESEL TRAVEL FRACTIONS

Table C-1. FRACTIONS OF AUTOMOBILE VMT ATTRIBUTED TO DIESEL VEHICLES UNDER SCENARIO D_2

Model Year Age of Vehicles	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	.001	.001	.002	.003	.006	.010	.016	.027	.040	.056	.071	.083	.092
2	.001	.001	.001	.002	.004	.007	.013	.022	.036	.054	.075	.095	.112
3	.001	.001	.001	.001	.002	.004	.007	.012	.021	.033	.050	.070	.089
4	.001	.001	.001	.001	.001	.002	.004	.006	.011	.019	.031	.046	.065
5	.001	.001	.001	.001	.001	.001	.002	.003	.006	.010	.017	.027	.041
6								.001	.003	.005	.008	.014	.023
7									.001	.002	.004	.007	.012
8										.001	.002	.003	.006
9											.001	.001	.003
10												.001	.001
11													
12													
13													
14													
15													
16													
17													
18													
19													
20+													
TOTALS	.005	.005	.006	.008	.014	.024	.042	.071	.118	.180	.259	.347	.444

TABLE C-1. (CONTINUED)

Model Year Age of Vehicles	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	.098	.101	.103	.105	.105	.106	.106	.106	.106	.106
2	.124	.131	.136	.139	.140	.141	.141	.142	.142	.142
3	.105	.116	.123	.127	.130	.131	.132	.132	.133	.133
4	.082	.097	.107	.114	.118	.120	.121	.122	.123	.123
5	.057	.072	.085	.094	.100	.103	.105	.107	.107	.108
6	.036	.048	.062	.072	.080	.085	.088	.090	.091	.091
7	.019	.029	.040	.052	.061	.067	.071	.074	.075	.076
8	.010	.016	.024	.034	.043	.050	.056	.059	.061	.062
9	.005	.008	.013	.019	.026	.033	.040	.044	.046	.048
10	.002	.003	.005	.009	.013	.018	.023	.028	.030	.032
11	.001	.001	.002	.004	.006	.009	.012	.016	.018	.020
12			.001	.001	.002	.004	.006	.008	.011	.013
13				.001	.001	.002	.003	.004	.005	.007
14						.001	.001	.002	.003	.004
15								.001	.001	.002
16										.001
17										
18										
19										
20+										
TOTALS	.539	.622	.701	.771	.825	.870	.905	.935	.952	.968

TABLE C-2. FRACTIONS OF HEAVY DUTY TRUCKS ON THE ROAD THAT ARE PROJECTED TO BE DIESEL

Vehicle Age Class	Combined Gas and Diesel HDT Registration Fractions	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
1	.069	.022	.022	.020	.026	.033	.037	.041	.045	.048	.052	.055	.057	.059	.061
2	.122	.037	.039	.038	.035	.046	.059	.066	.073	.079	.086	.091	.096	.096	.105
3	.123	.035	.037	.039	.039	.035	.046	.059	.066	.073	.080	.086	.092	.097	.102
4	.122	.032	.034	.037	.039	.038	.035	.046	.059	.066	.073	.079	.086	.091	.096
5	.094	.023	.025	.027	.028	.030	.030	.027	.035	.045	.051	.056	.061	.066	.070
6	.087	.019	.021	.023	.025	.026	.027	.027	.025	.033	.042	.047	.052	.057	.061
7	.081	.016	.018	.020	.021	.023	.025	.026	.026	.023	.031	.039	.044	.048	.053
8	.063	.011	.013	.014	.015	.017	.018	.019	.020	.020	.018	.024	.030	.034	.038
9	.048	.008	.009	.010	.011	.012	.013	.014	.015	.015	.015	.014	.018	.023	.026
10	.037	.005	.006	.007	.007	.008	.009	.010	.010	.011	.012	.012	.011	.014	.018
11	.028	.003	.004	.004	.005	.006	.006	.007	.007	.008	.008	.009	.009	.008	.011
12	.018	.002	.002	.003	.003	.003	.004	.004	.004	.005	.005	.005	.006	.006	.005
13	.017	.001	.002	.002	.002	.003	.003	.003	.004	.004	.004	.005	.005	.005	.005
14	.015	.001	.001	.001	.002	.002	.002	.003	.003	.003	.004	.004	.004	.005	.005
15	.014	.001	.001	.001	.001	.002	.002	.002	.003	.003	.003	.003	.004	.004	.004
16	.012	--	--	.001	.001	.001	.001	.002	.002	.002	.002	.003	.003	.003	.003
17	.011	--	--	--	.001	.001	.001	.001	.002	.002	.002	.002	.002	.003	.003
18	.010	--	--	--	--	.001	.001	.001	.001	.001	.002	.002	.002	.002	.002
19	.009	--	--	--	--	--	.001	.001	.001	.001	.001	.001	.002	.002	.002
20	.008	--	--	--	--	--	--	--	.001	.001	.001	.001	.001	.001	.002
TOTALS		.216	.234	.247	.261	.287	.320	.359	.402	.443	.492	.538	.588	.624	.677

TABLE C-2. (CONTINUED)

Vehicle Age Class	Combined Gas and Diesel HDT Registration Fractions	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	.069	.062	.064	.065	.066	.066	.067	.067	.068	.068	.068	.068	.068	.069	.069
2	.122	.108	.110	.113	.115	.116	.117	.118	.119	.120	.120	.120	.121	.121	.122
3	.123	.105	.109	.111	.114	.115	.117	.118	.119	.120	.121	.121	.121	.122	.122
4	.122	.096	.105	.108	.110	.113	.115	.116	.117	.118	.119	.120	.120	.120	.121
5	.094	.074	.078	.081	.083	.085	.087	.088	.089	.090	.091	.092	.092	.092	.093
6	.087	.065	.069	.072	.075	.077	.079	.080	.082	.083	.084	.084	.085	.085	.086
7	.081	.057	.061	.064	.064	.069	.072	.073	.075	.076	.077	.078	.078	.079	.079
8	.063	.041	.044	.047	.050	.050	.054	.056	.057	.058	.059	.060	.061	.061	.061
9	.048	.029	.031	.034	.036	.038	.038	.041	.042	.043	.044	.045	.046	.046	.047
10	.037	.020	.022	.024	.026	.028	.029	.029	.032	.033	.033	.034	.035	.035	.036
11	.028	.013	.015	.017	.018	.020	.021	.022	.022	.024	.025	.025	.026	.026	.027
12	.018	.007	.009	.010	.011	.012	.013	.013	.014	.014	.015	.016	.016	.017	.017
13	.017	.005	.006	.008	.009	.010	.011	.012	.013	.013	.013	.015	.015	.015	.016
14	.015	.005	.004	.006	.007	.008	.009	.010	.011	.011	.012	.012	.013	.013	.014
15	.014	.004	.004	.004	.005	.007	.008	.008	.009	.010	.010	.011	.011	.012	.012
16	.012	.004	.004	.004	.003	.005	.006	.006	.007	.008	.008	.009	.009	.009	.010
17	.011	.003	.003	.003	.003	.003	.004	.005	.006	.007	.007	.008	.008	.009	.009
18	.010	.003	.003	.003	.003	.003	.003	.004	.005	.005	.006	.007	.007	.007	.008
19	.009	.002	.002	.003	.003	.003	.003	.003	.003	.004	.005	.005	.006	.006	.007
20	.008	.002	.002	.002	.002	.002	.003	.003	.002	.003	.004	.004	.005	.005	.006
TOTALS		.705	.745	.779	.803	.830	.856	.872	.892	.908	.921	.934	.943	.949	.962

TABLE C-3-78. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.037	73,600	.032	19,000	3331.2	.098
2	.059	73,600	.063	19,000	5539.4	.157
3	.046	69,900	.077	17,900	4593.7	.116
4	.035	63,300	.087	16,500	3651.0	.080
5	.030	56,600	.064	15,000	2658.0	.061
6	.027	50,000	.060	13,500	2160.0	.049
7	.025	45,600	.056	12,000	1812.0	.041
8	.018	41,200	.045	10,600	1218.6	.027
9	.013	38,200	.035	9,500	829.1	.018
10	.009	36,000	.028	8,600	564.8	.012
11	.006	34,600	.022	7,800	379.2	.007
12	.004	33,800	.014	7,000	233.2	.005
13	.003	33,100	.014	6,300	187.5	.004
14	.002	32,400	.013	5,900	141.5	.002
15	.002	30,900	.012	5,300	125.4	.002
16	.001	28,700	.011	4,900	82.6	.001
17	.001	25,700	.010	4,700	72.7	.001
18	.001	21,300	.009	4,600	62.7	.001
19	.001	18,400	.008	4,400	53.6	.001
20	--	15,400	.008	4,200	33.6	--
					W_n = 27,729.8	.683 (Total)

TABLE C-3-79. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.041	73,600	.028	19,000	3549.6	.102
2	.066	73,600	.056	19,000	5921.6	.164
3	.059	69,900	.064	17,900	5269.7	.140
4	.046	63,300	.076	16,500	4165.8	.099
5	.027	56,600	.067	15,000	2533.2	.052
6	.027	50,000	.060	13,500	2160.0	.046
7	.026	45,600	.055	12,000	1845.6	.040
8	.019	41,200	.044	10,600	1249.2	.026
9	.014	38,200	.034	9,500	857.8	.018
10	.010	36,000	.027	8,600	592.2	.012
11	.007	34,600	.021	7,800	406.0	.008
12	.004	33,800	.014	7,000	233.2	.005
13	.003	33,100	.014	6,300	187.5	.003
14	.003	32,400	.012	5,900	168.0	.003
15	.002	30,900	.012	5,300	125.4	.002
16	.002	28,700	.010	4,900	106.4	.002
17	.001	25,700	.010	4,700	72.7	.001
18	.001	21,300	.009	4,600	62.7	.001
19	.001	18,400	.008	4,400	53.6	.001
20	--	15,400	.008	4,200	0	--
					W_n = 29,560.2	.725 (Total)

TABLE C-3-80. ESTIMATION OF DIESEL TRAVEL FRACTIONS
FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline		W_n (ab+ cd)	Diesel Travel Fractions
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate		
1	.045	73,600	.024	19,000	3768.0	.105
2	.073	73,600	.049	19,000	6303.8	.170
3	.066	69,900	.057	17,900	5633.7	.146
4	.059	63,300	.063	16,500	4774.2	.118
5	.035	56,600	.059	15,000	2866.0	.063
6	.025	50,000	.062	13,500	2087.0	.040
7	.026	45,600	.055	12,000	1845.6	.038
8	.020	41,200	.043	10,600	1279.8	.026
9	.015	38,200	.033	9,500	886.5	.018
10	.010	36,000	.027	8,600	592.2	.011
11	.007	34,600	.021	7,800	406.0	.008
12	.004	33,800	.014	7,000	233.2	.004
13	.004	33,100	.013	6,300	214.3	.004
14	.003	32,400	.012	5,900	168.0	.003
15	.003	30,900	.011	5,300	151.0	.003
16	.002	28,700	.010	4,900	106.4	.002
17	.002	25,700	.009	4,700	93.7	.002
18	.001	21,300	.009	4,600	62.7	.001
19	.001	18,400	.008	4,400	53.6	.001
20	.001	15,400	.007	4,200	44.8	—
					W_n = 31,570.5	.764 (Total)

TABLE C-3-81. ESTIMATION OF DIESEL TRAVEL FRACTIONS
FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline		W_n (ab+ cd)	Diesel Travel Fractions
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate		
1	.048	73,600	.021	19,000	3931.8	.106
2	.079	73,600	.043	19,000	6631.4	.174
3	.073	69,900	.050	17,900	5997.7	.153
4	.066	63,300	.056	16,500	5101.8	.125
5	.045	56,600	.049	15,000	3282.0	.076
6	.033	50,000	.054	13,500	2379.0	.049
7	.023	45,600	.058	12,000	1744.8	.031
8	.020	41,200	.043	10,600	1279.8	.025
9	.015	38,200	.033	9,500	886.5	.017
10	.011	36,000	.026	8,600	619.6	.012
11	.008	34,600	.020	7,800	432.8	.008
12	.005	33,800	.013	7,000	260.0	.005
13	.004	33,100	.013	6,300	214.3	.004
14	.003	32,400	.012	5,900	168.0	.003
15	.003	30,900	.011	5,300	151.0	.003
16	.002	28,700	.010	4,900	106.4	.002
17	.002	25,700	.009	4,700	93.7	.002
18	.001	21,300	.009	4,600	62.7	.001
19	.001	18,400	.008	4,400	53.6	.001
20	.001	15,400	.007	4,200	44.8	.001
					W_n = 33,441.7	.797 (Total)

TABLE C-3-82. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel (a) Fraction of Total HDT's	Diesel (b) Mileage Accumulation Rate	Gasoline (c) Fraction of Total HDT's	Gasoline (d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.052	73,600	.017	19,000	4150.2	.108
2	.086	73,600	.036	19,000	7013.6	.178
3	.080	69,900	.043	17,900	6361.7	.157
4	.073	63,300	.049	16,500	5429.4	.130
5	.051	56,600	.043	15,000	3531.6	.081
6	.042	50,000	.045	13,500	2707.5	.059
7	.031	45,600	.050	12,000	2013.6	.040
8	.018	41,200	.045	10,600	1218.6	.021
9	.015	38,200	.033	9,500	886.5	.016
10	.012	36,000	.025	8,600	647.0	.012
11	.008	34,600	.020	7,800	432.8	.008
12	.005	33,800	.013	7,000	260.0	.005
13	.004	33,100	.013	6,300	214.3	.004
14	.004	32,400	.011	5,900	194.5	.004
15	.003	30,900	.011	5,300	151.0	.003
16	.002	28,700	.010	4,900	106.4	.002
17	.002	25,700	.009	4,700	93.7	.001
18	.002	21,300	.008	4,600	79.4	.001
19	.001	18,400	.008	4,400	53.6	.001
20	.001	15,400	.007	4,200	44.8	--
					W_n = 35,590.2	.831 (Total)

TABLE C-3-83. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel (a) Fraction of Total HDT's	Diesel (b) Mileage Accumulation Rate	Gasoline (c) Fraction of Total HDT's	Gasoline (d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.055	73,600	.014	19,000	4314.0	.108
2	.091	73,600	.031	19,000	7286.6	.179
3	.086	69,900	.037	17,900	6673.7	.160
4	.079	63,300	.043	16,500	5710.2	.133
5	.056	56,600	.038	15,000	3739.6	.084
6	.047	50,000	.040	13,500	2890.0	.063
7	.039	45,600	.042	12,000	2282.4	.047
8	.024	41,200	.039	10,600	1402.2	.026
9	.014	38,200	.034	9,500	857.8	.014
10	.012	36,000	.025	8,600	647.0	.012
11	.009	34,600	.019	7,800	459.6	.008
12	.005	33,800	.013	7,000	260.0	.005
13	.005	33,100	.012	6,300	241.1	.004
14	.004	32,400	.011	5,900	194.5	.003
15	.003	30,900	.011	5,300	151.0	.002
16	.003	28,700	.009	4,900	130.2	.002
17	.002	25,700	.009	4,700	93.7	.001
18	.002	21,300	.008	4,600	79.4	.001
19	.001	18,400	.008	4,400	53.6	--
20	.001	15,400	.007	4,200	44.8	--
					W_n = 37,511.4	.852 (Total)

TABLE C-3-84. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline			
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab + cd)	Diesel Travel Fractions
1	.057	73,600	.012	19,000	4423.2	.106
2	.096	73,600	.026	19,000	7559.6	.179
3	.092	69,900	.031	17,900	6985.7	.163
4	.086	63,300	.036	16,500	6037.8	.138
5	.061	56,600	.033	15,000	3947.6	.088
6	.052	50,000	.035	13,500	3072.5	.066
7	.044	45,600	.037	12,000	2450.4	.051
8	.030	41,200	.033	10,600	1585.8	.031
9	.018	38,200	.030	9,500	972.6	.017
10	.011	36,000	.026	8,600	619.6	.010
11	.009	34,600	.019	7,800	459.6	.008
12	.006	33,800	.012	7,000	286.8	.005
13	.005	33,100	.012	6,300	241.1	.004
14	.004	32,400	.011	5,900	194.5	.003
15	.004	30,900	.010	5,300	176.6	.003
16	.003	28,700	.009	4,900	130.2	.002
17	.002	25,700	.009	4,700	93.7	.001
18	.002	21,300	.008	4,600	79.4	.001
19	.002	18,400	.007	4,400	67.9	.001
20	.001	15,400	.007	4,200	44.8	--
					W_n = 39,429.1	.877 (Total)

TABLE C-3-85. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline			
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab + cd)	Diesel Travel Fractions
1	.059	73,600	.010	19,000	4532.4	.106
2	.096	73,600	.026	19,000	7559.6	.173
3	.097	69,900	.026	17,900	7245.7	.166
4	.091	63,300	.031	16,500	6271.8	.141
5	.066	56,600	.028	15,000	4155.6	.091
6	.057	50,000	.030	13,500	3255.0	.070
7	.048	45,600	.033	12,000	2584.8	.053
8	.034	41,200	.029	10,600	1708.2	.034
9	.023	38,200	.025	9,500	1116.1	.021
10	.014	36,000	.023	8,600	701.8	.012
11	.008	34,600	.020	7,800	432.8	.007
12	.006	33,800	.012	7,000	286.8	.005
13	.005	33,100	.012	6,300	241.1	.004
14	.005	32,400	.010	5,900	221.0	.004
15	.004	30,900	.010	5,300	176.6	.003
16	.003	28,700	.009	4,900	130.2	.002
17	.003	25,700	.008	4,700	114.7	.002
18	.002	21,300	.008	4,600	79.4	.001
19	.002	18,400	.007	4,400	67.6	.001
20	.001	15,400	.007	4,200	44.8	--
					W_n = 40,926.0	.896 (Total)

TABLE C-3-86. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab + cd)	Diesel Travel Fractions
1	.061	73,600	.008	19,000	4641.6	.105
2	.105	73,600	.017	19,000	8051.0	.181
3	.097	69,900	.026	17,900	7245.7	.159
4	.096	63,300	.026	16,500	6505.8	.143
5	.070	56,600	.024	15,000	4322.0	.093
6	.061	50,000	.026	13,500	3401.0	.072
7	.053	45,600	.028	12,000	2752.8	.057
8	.038	41,200	.025	10,600	1830.6	.037
9	.026	38,200	.022	9,500	1202.2	.023
10	.018	36,000	.019	8,600	811.4	.015
11	.011	34,600	.017	7,800	513.2	.009
12	.005	33,800	.013	7,000	260.0	.004
13	.005	33,100	.012	6,300	241.1	.004
14	.005	32,400	.010	5,900	221.0	.004
15	.004	30,900	.010	5,300	176.6	.003
16	.003	28,700	.009	4,900	130.2	.002
17	.003	25,700	.008	4,700	114.7	.002
18	.002	21,300	.008	4,600	79.4	.001
19	.002	18,400	.007	4,400	67.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 42,623.9	.916 (TOtal)

TABLE C-3-87. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab + cd)	Diesel Travel Fractions
1	.062	73,600	.007	19,000	4696.2	.104
2	.108	73,600	.014	19,000	8214.8	.180
3	.105	69,900	.018	17,900	7661.7	.166
4	.096	63,300	.026	16,500	6505.8	.138
5	.074	56,600	.020	15,000	4488.4	.095
6	.065	50,000	.022	13,500	3547.0	.074
7	.057	45,600	.024	12,000	2887.2	.059
8	.041	41,200	.022	10,600	1922.4	.038
9	.029	38,200	.019	9,500	1288.3	.025
10	.020	36,000	.017	8,600	866.2	.016
11	.013	34,600	.015	7,800	566.8	.010
12	.007	33,800	.011	7,000	313.6	.005
13	.005	33,100	.012	6,300	241.1	.004
14	.005	32,400	.010	5,900	221.0	.004
15	.004	30,900	.010	5,300	176.6	.003
16	.004	28,700	.008	4,900	154.0	.003
17	.003	25,700	.008	4,700	114.7	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.002	18,400	.007	4,400	67.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 44,085.5	.929 (Total)

TABLE C-3-88. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline		W_n (ab+ cd)	Diesel Travel Fractions
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate		
1	.064	73,600	.005	19,000	4805.4	.103
2	.110	73,600	.012	19,000	8324.0	.177
3	.109	69,900	.014	17,900	7869.7	.167
4	.105	63,300	.017	16,500	6927.0	.145
5	.078	56,600	.016	15,000	4654.8	.097
6	.069	50,000	.018	13,500	3693.0	.076
7	.061	45,600	.020	12,000	3021.6	.061
8	.044	41,200	.019	10,600	2014.2	.040
9	.031	38,200	.017	9,500	1345.7	.026
10	.022	36,000	.015	8,600	921.0	.017
11	.015	34,600	.013	7,800	620.4	.011
12	.009	33,800	.009	7,000	367.2	.007
13	.006	33,100	.011	6,300	267.9	.004
14	.004	32,400	.011	5,900	194.5	.003
15	.004	30,900	.010	5,300	176.6	.003
16	.004	28,700	.008	4,900	154.0	.003
17	.003	25,700	.008	4,700	114.7	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.002	18,400	.007	4,400	67.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 45,691.4	.945 (Total)

TABLE C-3-89. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline		W_n (ab+ cd)	Diesel Travel Fractions
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate		
1	.065	73,600	.004	19,000	4955.0	.102
2	.113	73,600	.009	19,000	8487.8	.177
3	.111	69,900	.012	17,900	7973.7	.165
4	.108	63,300	.014	16,500	7067.4	.145
5	.081	56,600	.013	15,000	4779.6	.098
6	.072	50,000	.015	13,500	3802.5	.077
7	.064	45,600	.017	12,000	3122.4	.062
8	.047	41,200	.016	10,600	2106.0	.041
9	.034	38,200	.014	9,500	1431.8	.028
10	.024	36,000	.013	8,600	975.8	.018
11	.017	34,600	.011	7,800	674.0	.013
12	.010	33,800	.008	7,000	394.0	.007
13	.008	33,100	.009	6,300	321.5	.006
14	.006	32,400	.009	5,900	247.5	.004
15	.004	30,900	.010	5,300	176.6	.003
16	.004	28,700	.008	4,900	154.0	.002
17	.003	25,700	.008	4,700	114.7	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.003	18,400	.006	4,400	81.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 47,018.0	.953 (Total)

TABLE C-3-90. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.066	73,600	.003	19,000	4914.6	.102
2	.115	73,600	.007	19,000	8597.0	.177
3	.114	69,900	.009	17,900	8129.7	.167
4	.110	63,300	.012	16,500	7161.0	.146
5	.083	56,600	.011	15,000	4862.8	.098
6	.075	50,000	.012	13,500	3912.0	.078
7	.064	45,600	.017	12,000	3122.4	.061
8	.050	41,200	.013	10,600	2197.8	.043
9	.036	38,200	.012	9,500	1489.2	.029
10	.026	36,000	.011	8,600	1030.6	.020
11	.018	34,600	.010	7,800	700.8	.013
12	.011	33,800	.007	7,000	420.8	.008
13	.009	33,100	.008	6,300	348.3	.006
14	.007	32,400	.008	5,900	274.0	.005
15	.005	30,900	.009	5,300	202.2	.003
16	.003	28,700	.009	4,900	130.2	.002
17	.003	25,700	.008	4,700	114.7	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.003	18,400	.006	4,400	81.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 47,841.8	.963 (Total)

TABLE C-3-91. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.066	73,600	.003	19,000	4914.6	.100
2	.116	73,600	.006	19,000	8651.6	.175
3	.115	69,900	.008	17,900	8181.7	.165
4	.113	63,300	.009	16,500	7301.4	.147
5	.085	56,600	.009	15,000	4946.0	.099
6	.077	50,000	.010	13,500	3985.0	.079
7	.069	45,600	.012	12,000	3290.4	.065
8	.050	41,200	.013	10,600	2197.8	.042
9	.038	38,200	.010	9,500	1546.6	.030
10	.028	36,000	.009	8,600	1085.4	.021
11	.020	34,600	.008	7,800	754.4	.014
12	.012	33,800	.006	7,000	447.6	.008
13	.010	33,100	.007	6,300	375.1	.007
14	.008	32,400	.007	5,900	300.5	.005
15	.007	30,900	.007	5,300	253.4	.004
16	.005	28,700	.007	4,900	177.8	.003
17	.003	25,700	.008	4,700	114.7	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.003	18,400	.006	4,400	81.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 48,757.7	.969 (Total)

TABLE C-3-92. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.067	73,600	.002	19,000	4969.2	.099
2	.117	73,600	.005	19,000	8706.2	.173
3	.117	69,900	.006	17,900	8285.7	.165
4	.115	63,300	.007	16,500	7395.0	.147
5	.087	56,600	.007	15,000	5029.2	.099
6	.079	50,000	.008	13,500	4058.0	.080
7	.072	45,600	.009	12,000	3391.2	.066
8	.054	41,200	.009	10,600	2320.2	.045
9	.038	38,200	.010	9,500	1546.6	.029
10	.029	36,000	.009	8,600	1121.4	.021
11	.021	34,600	.007	7,800	781.2	.015
12	.013	33,800	.005	7,000	474.4	.009
13	.011	33,100	.006	6,300	401.9	.007
14	.009	32,400	.006	5,900	327.0	.006
15	.008	30,900	.006	5,300	279.0	.005
16	.006	28,700	.006	4,900	201.6	.003
17	.004	25,700	.006	4,700	131.0	.002
18	.003	21,300	.007	4,600	96.1	.001
19	.003	18,400	.006	4,400	81.6	.001
20	.003	15,400	.005	4,200	67.2	.001
					W_n = 49,663.7	.974 (Total)

TABLE C-3-93. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.067	73,600	.002	19,000	4969.2	.098
2	.118	73,600	.004	19,000	8760.8	.173
3	.118	69,900	.005	17,900	8337.7	.164
4	.116	63,300	.006	16,500	7441.8	.146
5	.088	56,600	.006	15,000	5070.8	.099
6	.080	50,000	.007	13,500	4094.5	.080
7	.073	45,600	.008	12,000	3424.8	.066
8	.056	41,200	.007	10,600	2381.4	.046
9	.041	38,200	.007	9,500	1632.7	.031
10	.029	36,000	.008	8,600	1112.8	.021
11	.022	34,600	.006	7,800	808.0	.015
12	.013	33,800	.005	7,000	474.4	.009
13	.012	33,100	.005	6,300	428.7	.008
14	.010	32,400	.005	5,900	353.5	.006
15	.008	30,900	.006	5,300	279.0	.005
16	.006	28,700	.006	4,900	201.6	.003
17	.005	25,700	.006	4,700	156.7	.003
18	.004	21,300	.006	4,600	112.8	.002
19	.003	18,400	.006	4,400	81.6	.001
20	.003	15,400	.005	4,200	67.2	.001
					W_n = 50,190.0	.977 (Total)

TABLE C-3-94. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.068	73,600	.001	19,000	5023.8	.098
2	.119	73,600	.003	19,000	8815.4	.172
3	.119	69,900	.004	17,900	8389.7	.163
4	.117	63,300	.005	16,500	7488.6	.145
5	.089	56,600	.005	15,000	5112.4	.099
6	.082	50,000	.005	13,500	4167.5	.081
7	.075	45,600	.006	12,000	3492.0	.067
8	.057	41,200	.006	10,600	2412.0	.046
9	.042	38,200	.006	9,500	1661.4	.032
10	.032	36,000	.005	8,600	1195.0	.023
11	.022	34,600	.006	7,800	808.0	.015
12	.014	33,800	.004	7,000	501.2	.009
13	.013	33,100	.004	6,300	455.5	.008
14	.011	32,400	.004	5,900	380.0	.007
15	.009	30,900	.005	5,300	304.6	.005
16	.007	28,700	.005	4,900	225.4	.004
17	.006	25,700	.005	4,700	177.7	.003
18	.005	21,300	.005	4,600	129.5	.002
19	.003	18,400	.006	4,400	81.6	.001
20	.002	15,400	.006	4,200	56.0	.001
					W_n = 50,907.3	.981 (Total)

TABLE C-3-95. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.068	73,600	.001	19,000	5023.8	.097
2	.120	73,600	.002	19,000	8870.0	.172
3	.120	69,900	.003	17,900	8441.7	.163
4	.118	63,300	.004	16,500	7535.4	.145
5	.090	56,600	.004	15,000	5154.0	.099
6	.083	50,000	.004	13,500	4204.0	.081
7	.076	45,600	.005	12,000	3525.6	.067
8	.058	41,200	.005	10,600	2442.6	.047
9	.043	38,200	.005	9,500	1690.1	.032
10	.033	36,000	.004	8,600	1222.4	.023
11	.024	34,600	.004	7,800	861.6	.016
12	.014	33,800	.004	7,000	501.2	.009
13	.013	33,100	.004	6,300	455.5	.008
14	.011	32,400	.004	5,900	380.0	.007
15	.010	30,900	.004	5,300	330.2	.006
16	.008	28,700	.004	4,900	249.2	.004
17	.007	25,700	.004	4,700	198.7	.004
18	.005	21,300	.005	4,600	129.5	.002
19	.004	18,400	.005	4,400	95.6	.001
20	.003	15,400	.005	4,200	67.2	.001
					W_n = 51,378.3	.984 (Total)

TABLE C-3-96. ESTIMATION OF DIESEL TRAVEL FRACTIONS
FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.068	73,600	.001	19,000	5023.8	.097
2	.120	73,600	.002	19,000	8870.0	.171
3	.121	69,900	.002	17,900	8493.7	.163
4	.119	63,300	.003	16,500	7582.2	.146
5	.091	56,600	.003	15,000	5195.6	.099
6	.084	50,000	.003	13,500	4240.5	.081
7	.077	45,600	.004	12,000	3559.2	.068
8	.059	41,200	.004	10,600	2473.2	.047
9	.044	38,200	.004	9,500	1718.8	.032
10	.033	36,000	.004	8,600	1222.4	.023
11	.025	34,600	.003	7,800	888.4	.017
12	.015	33,800	.003	7,000	528.0	.010
13	.013	33,100	.004	6,300	455.5	.008
14	.012	32,400	.003	5,900	406.5	.008
15	.010	30,900	.004	5,300	330.2	.006
16	.008	28,700	.004	4,900	249.2	.004
17	.007	25,700	.004	4,700	198.7	.003
18	.006	21,300	.004	4,600	146.2	.002
19	.005	18,400	.004	4,400	109.6	.002
20	.004	15,400	.004	4,200	78.4	.001
					W_n = 51,770.1	.988 (Total)

TABLE C-3-97. ESTIMATION OF DIESEL TRAVEL FRACTIONS
FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.068	73,600	.001	19,000	5023.8	.096
2	.120	73,600	.002	19,000	8870.0	.169
3	.121	69,900	.002	17,900	8493.7	.162
4	.120	63,300	.002	16,500	7629.0	.146
5	.092	56,600	.002	15,000	5237.2	.100
6	.084	50,000	.003	13,500	4240.5	.081
7	.078	45,600	.003	12,000	3592.8	.068
8	.060	41,200	.003	10,600	2503.8	.047
9	.045	38,200	.003	9,500	1747.5	.033
10	.034	36,000	.003	8,600	1249.8	.023
11	.025	34,600	.003	7,800	888.4	.017
12	.016	33,800	.002	7,000	554.8	.010
13	.015	33,100	.002	6,300	509.1	.010
14	.012	32,400	.003	5,900	406.5	.007
15	.011	30,900	.003	5,300	355.8	.007
16	.009	28,700	.003	4,900	273.0	.005
17	.008	25,700	.003	4,700	219.7	.004
18	.007	21,300	.003	4,600	162.9	.003
19	.005	18,400	.004	4,400	109.6	.002
20	.004	15,400	.004	4,200	78.4	.001
					W_n = 52,146.3	.991 (Total)

TABLE C-3-98. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline			
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.068	73,600	.001	19,000	5023.8	.096
2	.121	73,600	.001	19,000	8924.6	.170
3	.121	69,900	.002	17,900	8493.7	.161
4	.120	63,300	.002	16,500	7629.0	.145
5	.092	56,600	.002	15,000	5237.2	.099
6	.085	50,000	.002	13,500	4277.0	.081
7	.078	45,600	.003	12,000	3592.8	.068
8	.061	41,200	.002	10,600	2534.4	.048
9	.046	38,200	.002	9,500	1776.2	.034
10	.035	36,000	.002	8,600	1277.2	.024
11	.026	34,600	.002	7,800	915.2	.017
12	.016	33,800	.002	7,000	554.8	.010
13	.015	33,100	.002	6,300	509.1	.009
14	.013	32,400	.002	5,900	433.0	.008
15	.011	30,900	.003	5,300	355.8	.006
16	.009	28,700	.003	4,900	273.0	.005
17	.008	25,700	.003	4,700	219.7	.004
18	.007	21,300	.003	4,600	162.9	.003
19	.006	18,400	.003	4,400	123.6	.002
20	.005	15,400	.003	4,200	89.6	.001
					W_n = 52,402.6	.991 (Total

TABLE C-3-99. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

Vehicle Age	Diesel		Gasoline			
	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.069	73,600	—	19,000	5078.4	.097
2	.121	73,600	.001	19,000	8924.6	.169
3	.122	69,900	.001	17,900	8545.7	.162
4	.120	63,300	.002	16,500	7629.0	.144
5	.092	56,600	.002	15,000	5237.2	.099
6	.085	50,000	.002	13,500	4277.0	.081
7	.079	45,600	.002	12,000	3626.4	.068
8	.061	41,200	.002	10,600	2534.4	.048
9	.046	38,200	.002	9,500	1776.2	.035
10	.035	36,000	.002	8,600	1277.2	.024
11	.026	34,600	.002	7,800	915.2	.017
12	.017	33,800	.001	7,000	581.6	.011
13	.015	33,100	.002	6,300	509.1	.009
14	.013	32,400	.002	5,900	433.0	.008
15	.012	30,900	.002	5,300	381.4	.007
16	.009	28,700	.003	4,900	273.0	.005
17	.009	25,700	.002	4,700	240.7	.004
18	.007	21,300	.003	4,600	162.9	.003
19	.006	18,400	.003	4,400	123.6	.002
20	.005	15,400	.003	4,200	89.6	.001
					W_n = 52,616.2	.992 (Total)

TABLE G-3-2000. ESTIMATION OF DIESEL TRAVEL FRACTIONS FOR THE HDT PROJECTED SALES SCENARIO.

	Diesel		Gasoline			
Vehicle Age	(a) Fraction of Total HDT's	(b) Mileage Accumulation Rate	(c) Fraction of Total HDT's	(d) Mileage Accumulation Rate	W_n (ab+ cd)	Diesel Travel Fractions
1	.069	73,600	--	19,000	5078.4	.096
2	.122	73,600	--	19,000	8979.2	.169
3	.122	69,900	.001	17,900	8545.7	.161
4	.121	63,300	.001	16,500	7675.8	.145
5	.093	56,600	.001	15,000	5278.8	.099
6	.086	50,000	.001	13,500	4313.5	.081
7	.079	45,600	.002	12,000	3626.4	.068
8	.061	41,200	.002	10,600	2534.4	.047
9	.047	38,200	.001	9,500	1804.9	.034
10	.036	36,000	.001	8,600	1304.6	.024
11	.027	34,600	.001	7,800	942.0	.018
12	.017	33,800	.001	7,000	581.6	.011
13	.016	33,100	.001	6,300	535.9	.010
14	.014	32,400	.001	5,900	459.5	.009
15	.012	30,900	.002	5,300	381.4	.007
16	.010	28,700	.002	4,900	296.8	.005
17	.009	25,700	.002	4,700	240.7	.004
18	.008	21,300	.002	4,600	179.6	.003
19	.007	18,400	.002	4,400	137.6	.002
20	.006	15,400	.002	4,200	100.8	.002
					W_n = 52,997.6	.995 (Total)

TABLE D. TABLES OF PROJECTED EMISSION FACTORS

TABLE D-1. TRAVEL WEIGHTED AUTOMOBILE PARTICULATE EMISSION FACTORS FOR SCENARIO E_1D_2

Vehicle Age Class	Age Class Travel Fraction	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	.106	.001	.001	.002	.002	.004	.006	.009	.014	.021	.028	.036	.042	.046
2	.142	.002	.002	.002	.002	.003	.005	.008	.012	.019	.028	.038	.048	.056
3	.133	.002	.002	.002	.002	.002	.003	.005	.007	.011	.017	.026	.036	.045
4	.123	.002	.002	.002	.002	.002	.002	.003	.004	.006	.010	.016	.024	.033
5	.108	.027	.001	.001	.001	.001	.001	.002	.002	.004	.006	.009	.014	.021
6	.092	.023	.023	.001	.001	.001	.001	.001	.001	.002	.003	.005	.008	.012
7	.077	.019	.019	.019	.001	.001	.001	.001	.001	.001	.002	.003	.004	.007
8	.064	.016	.016	.016	.016	.001	.001	.001	.001	.001	.001	.002	.002	.004
9	.050	.013	.013	.013	.013	.013	--	--	--	--	--	.001	.001	.002
10	.035	.009	.009	.009	.009	.009	.009	--	--	--	--	--	.001	.001
11	.023	.006	.006	.006	.006	.006	.006	.006	--	--	--	--	--	--
12	.016	.004	.004	.004	.004	.004	.004	.004	.004	--	--	--	--	--
13	.010	.003	.003	.003	.003	.003	.003	.003	.003	.003	--	--	--	--
14	.007	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	--	--	--
15	.004	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--	--
16	.003	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--
17	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
18	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
19	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
20	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
TOTALS	1.001	.135	.109	.088	.070	.058	.050	.051	.057	.076	.103	.142	.185	.231

TABLE D-1. (CONTINUED)

Vehicle Age Class	Age Class Travel Fraction	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	.106	.049	.051	.052	.053	.053	.053	.053	.053	.053	.053
2	.142	.062	.066	.068	.070	.070	.071	.071	.071	.071	.071
3	.133	.053	.058	.062	.064	.065	.066	.062	.067	.067	.067
4	.123	.041	.049	.054	.057	.059	.060	.061	.061	.062	.062
5	.108	.029	.036	.043	.047	.050	.052	.053	.054	.054	.054
6	.092	.018	.024	.031	.036	.040	.043	.044	.045	.046	.046
7	.077	.010	.015	.020	.026	.031	.034	.036	.037	.038	.038
8	.064	.005	.008	.012	.017	.022	.025	.028	.030	.031	.031
9	.050	.003	.004	.007	.010	.013	.017	.020	.022	.023	.024
10	.035	.001	.002	.003	.005	.007	.009	.012	.014	.015	.016
11	.023	.001	.001	.001	.002	.003	.005	.006	.008	.009	.010
12	.016	--	--	.001	.001	.001	.002	.003	.004	.006	.007
13	.010	--	--	--	.001	.001	.001	.002	.002	.003	.004
14	.007	--	--	--	--	--	.001	.001	.001	.002	.002
15	.004	--	--	--	--	--	--	--	.001	.001	.001
16	.003	--	--	--	--	--	--	--	--	--	.001
17	.002	--	--	--	--	--	--	--	--	--	--
18	.002	.001	--	--	--	--	--	--	--	--	--
19	.002	.001	.001	--	--	--	--	--	--	--	--
20	.002	.001	.001	.001	--	--	--	--	--	--	--
TOTALS	1.001	.275	.316	.355	.389	.415	.439	.452	.470	.481	.487

TABLE D-2. TRAVEL WEIGHTED AUTOMOBILE PARTICULATE EMISSION FACTORS FOR SCENARIO E_1D_1

Vehicle Age Class	Age Class Travel Fraction	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	.106	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
2	.142	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
3	.133	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
4	.123	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
5	.108	.027	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
6	.092	.023	.023	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
7	.077	.019	.019	.019	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
8	.064	.016	.016	.016	.016	.001	.001	.001	.001	.001	.001	.001	.001	.001
9	.050	.013	.013	.013	.013	.013	--	--	--	--	--	--	--	--
10	.035	.009	.009	.009	.009	.009	.009	--	--	--	--	--	--	--
11	.023	.006	.006	.006	.006	.006	.006	.006	--	--	--	--	--	--
12	.016	.004	.004	.004	.004	.004	.004	.004	.004	--	--	--	--	--
13	.010	.003	.003	.003	.003	.003	.003	.003	.003	.003	--	--	--	--
14	.007	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	--	--	--
15	.004	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--	--
16	.003	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--
17	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
18	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
19	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
20	.002	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
TOTALS		.132	.106	.084	.066	.051	.038	.029	.023	.019	.016	.014	.013	.012

TABLE D-2. (CONTINUED)

Vehicle Age Class	Age Class Travel Fraction	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	.106	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
2	.142	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
3	.133	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
4	.123	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
5	.108	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
6	.092	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
7	.077	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
8	.064	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
9	.050	--	--	--	--	--	--	--	--	--	--
10	.035	--	--	--	--	--	--	--	--	--	--
11	.023	--	--	--	--	--	--	--	--	--	--
12	.016	--	--	--	--	--	--	--	--	--	--
13	.010	--	--	--	--	--	--	--	--	--	--
14	.007	--	--	--	--	--	--	--	--	--	--
15	.004	--	--	--	--	--	--	--	--	--	--
16	.003	--	--	--	--	--	--	--	--	--	--
17	.002	--	--	--	--	--	--	--	--	--	--
18	.002	.001	--	--	--	--	--	--	--	--	--
19	.002	.001	.001	--	--	--	--	--	--	--	--
20	.002	.001	.001	.001	--	--	--	--	--	--	--
TOTALS		.011	.010	.009	.008	.008	.008	.008	.008	.008	.008

TABLE D-3. TRAVEL WEIGHTED AND MODEL YEAR WEIGHTED GASOLINE HDT PARTICULATE EMISSION FACTORS UNDER SCENARIO E_1 BY VEHICLE AGE CLASS AND BY PROJECTION YEAR

Vehicle Age Class	Gasoline HDT Travel Fractions	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
1	.061	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
2	.116	.037	.037	.037	.037	.037	.037	.037	.037	.037	.037	.037	.037	.037
3	.122	.039	.039	.039	.039	.039	.039	.039	.039	.039	.039	.039	.039	.039
4	.124	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040
5	.098	.088	.031	.031	.031	.031	.031	.031	.031	.031	.031	.031	.031	.031
6	.088	.079	.079	.028	.028	.028	.028	.028	.028	.028	.028	.028	.028	.028
7	.079	.071	.071	.071	.025	.025	.025	.025	.025	.025	.025	.025	.025	.025
8	.063	.057	.057	.057	.057	.020	.020	.020	.020	.020	.020	.020	.020	.020
9	.049	.044	.044	.044	.044	.044	.016	.016	.016	.016	.016	.016	.016	.016
10	.040	.036	.036	.036	.036	.036	.036	.013	.013	.013	.013	.013	.013	.013
11	.030	.027	.027	.027	.027	.027	.027	.027	.010	.010	.010	.010	.010	.010
12	.020	.018	.018	.018	.018	.018	.018	.018	.018	.006	.006	.006	.006	.006
13	.021	.019	.019	.019	.019	.019	.019	.019	.019	.019	.007	.007	.007	.007
14	.019	.017	.017	.017	.017	.017	.017	.017	.017	.017	.017	.006	.006	.006
15	.016	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.005	.005
16	.014	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013	.004
17	.012	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011	.011
18	.011	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
19	.010	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009
20	.009	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008	.008
TOTALS		.657	.600	.549	.503	.466	.438	.415	.398	.386	.374	.363	.354	.345

TABLE D-3. (CONTINUED)

Vehicle Age Class	Gasoline HDT Travel Fractions	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
1	.061	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
2	.116	.037	.037	.037	.037	.037	.037	.037	.037	.037	.037
3	.122	.039	.039	.039	.039	.039	.039	.039	.039	.309	.039
4	.124	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040
5	.098	.031	.031	.031	.031	.031	.031	.031	.031	.031	.031
6	.088	.028	.028	.028	.028	.028	.028	.028	.028	.028	.028
7	.079	.025	.025	.025	.025	.025	.025	.025	.025	.025	.025
8	.063	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
9	.049	.016	.016	.016	.016	.016	.016	.016	.016	.016	.016
10	.040	.013	.013	.013	.013	.013	.013	.013	.013	.013	.013
11	.030	.010	.010	.010	.010	.010	.010	.010	.010	.010	.010
12	.020	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006
13	.021	.007	.007	.007	.007	.007	.007	.007	.007	.007	.007
14	.019	.006	.006	.006	.006	.006	.006	.006	.006	.006	.006
15	.016	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005
16	.014	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
17	.012	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
18	.011	.010	.004	.004	.004	.004	.004	.004	.004	.004	.004
19	.010	.009	.009	.003	.003	.003	.003	.003	.003	.003	.003
20	.009	.008	.008	.008	.003	.003	.003	.003	.003	.003	.003
TOTALS		.338	.332	.326	.321	.321	.321	.321	.321	.321	.321

TABLE D-4. PROJECTED PARTICULATE EMISSIONS FOR HEAVY DUTY TRUCKS[a]

Year	Projected Diesel Travel Fractions	Diesel Emission Factor	Weighted Gasoline Emission Factors	Projected Emissions g/n-VMT
1978	.683	2.0	.657	1.57
1979	.725	2.0	.600	1.62
1980	.764	2.0	.549	1.66
1981	.797	2.0	.503	1.70
1982	.831	2.0	.466	1.74
1983	.852	2.0	.438	1.77
1984	.877	2.0	.415	1.81
1985	.896	2.0	.398	1.83
1986	.916	2.0	.386	1.86
1987	.929	2.0	.374	1.88
1988	.945	2.0	.363	1.91
1989	.953	2.0	.354	1.92
1990	.963	2.0	.345	1.94
1991	.969	2.0	.338	1.95
1992	.974	2.0	.332	1.96
1993	.977	2.0	.326	1.96
1994	.981	2.0	.321	1.97
1995	.984	2.0	.321	1.97
1996	.988	2.0	.321	1.98
1997	.991	2.0	.321	1.98
1998	.991	2.0	.321	1.98
1999	.992	2.0	.321	1.99
2000	.995	2.0	.321	1.99

[a] Gas and diesel trucks combined.

APPENDIX E. A ROUTINE FOR PROJECTING MEAN ANNUAL TSP

APPENDIX E. A ROUTINE FOR PROJECTING MEAN ANNUAL TSP

The chapters preceeding the appendixes have discussed the procedures used to calculate the parameters that determine the projected vehicular emissions and the projected total suspended particulate (TSP) levels. While calculating these values entails considerable work, it may be desirable to analyze additional transportation scenarios, additional diesel sales scenarios, or other diesel emission factors. Since the number of scenario combinations is the product of the number of alternatives in each scenario component, the addition of any one component multiplies the amount of additional computation. Clearly, it is desirable to computerize the computational steps so that additional calculations may be accomplished quickly and easily.

In this appendix the computations used in this report are derived as a sequence of computational steps which could be thought of as subroutines for a computer program. These steps could be expressed in a single holistic formula (a one or two-page equation), but such an unwieldy expression is less useful than a step-by-step sequence.

To be most useful, the formulae have been constructed so that all inputs can be taken directly from one of the tables in this report or from a scenario description parameter. For example, transportation scenarios are expressed as presumed linear growth rates for various modes of transportation; therefore, these growth rates will be one of the inputs. Diesel sales are taken from a logistic distribution function; therefore, the presumed points on the logistic curve are inputs for these computations. Emission rates are not presently known with certainty, so their presumed values are scenario inputs for some of the computational steps.

In this study we have established the following relationship for the base year B 1976. For convenience, the base year for emissions estimates is also considered a standard meteorological year.

(1) $$\frac{\bar{X}_B}{Q_B} = k_B$$

where

$\bar{X}_B$ = the geometric mean of samples taken at a monitoring site during 1975-1977 and normalized to a standard meteorological year.

Q_B = the total TSP emissions effective at a given monitoring site in base year (B).

Since the standard meteorological year B is assumed to hold for all projection years, the relationship between $\bar{X}$ and Q holds for all projection years.

For projection year Y, the expression is as follows:

(2) $$\frac{\bar{X}_Y}{Q_Y} = k_B$$

The TSP emissions Q that affect a given monitoring site are the sum of the vehicle emissions and the non-vehicular emissions. Since the vehicle emissions are the ones of concern, it is desirable to express them in a separate term, as follows:

(3) $$\frac{\bar{X}_Y}{E_Y+E_{oY}} = k_B$$

where

E_Y = vehicle particulate emission in year Y, and

E_o = other particulate emissions in year Y.

However, since the object of study is the vehicular emissions (E_Y) and their effects on ambient TSP levels, it is assumed that all non-vehicular emissions remain constant. In other words, $E_{oY} = E_{oB}$. Therefore, the following is also true:

(4) $$\frac{\bar{X}_Y}{E_Y+E_{oB}} = k_B$$

Note that E_Y depends upon the conditions that are set out in a particular scenario composition $(T_s D_s E_s)$ for the projection year Y, while E_{oB} and k_B are fixed by the normalized empirical relationship found in the base year. It is not important to know the exact value of either E_Y or E_{oB}, but it is very important to know the relationship between E_Y and E_{oB} in the base year (because $E_Y + E_{oB} = Q_B$ fixes the value of k_B) and the change in E for any projection year with respect to the base year (because this change determines the value of $\bar{\chi}$ in the projection year).

Through trace element studies it was found that vehicle emissions in the base year E_B represent a certain proportion p of the total emissions. (See Chapter 5.) Thus, the ratio of vehicle emissions to all other emissions can be expressed as follows:

$$(5) \qquad \frac{E_B}{E_{oB}} = \frac{p}{1-p}$$

where

E_B = emissions from vehicles in the base year B,

E_{oB} = emissions from sources other than vehicles in the base year B,

p = the proportion of the particulate emissions from motorized vehicles in the base year B, and

1-p = the proportion of the particulate emissions from all other (non-vehicular) emissions in the base year B.

By rearrangement of terms, E_{oB} can be expressed as a function of p and E_B and then substituted into Equation 4 as follows:

$$(6) \qquad \frac{\bar{\chi}_Y}{E_Y + E_B\left(\frac{1-p}{p}\right)} = k_B$$

However, from Equations 2, 3, and 6 we have the following relationships:

$$(7) \qquad k_b = \frac{\bar{\chi}_B}{Q_B} = \frac{\bar{\chi}_B}{E_B + E_{oB}} = \frac{\bar{\chi}_B}{E_B + E_B\left(\frac{1-p}{p}\right)}$$

This expression for k_b can be substituted into Equation 6. Then, solving for $\bar{X}_Y$:

$$(8) \qquad \bar{X}_Y = \frac{\bar{X}_B \left(E_Y + E_B(\frac{1 - p}{p})\right)}{E_Y + E_B(\frac{1 - p}{p})}$$

Equation 8 is a convenient formula for the estimation of the geometric mean TSP for any projection year Y. It is based upon data from the base year and from the conditions of a certain scenario composition.

By examination of Equation 8 it is found that the dimensions of E_Y are irrelevant. What is important is the size of E_Y in respect to E_B. For this reason some of the parameters used in the calculations are either dimensionless or are expressed as fractions of base year data.

In addition to estimating the total TSP level for a given projection year ($\bar{X}_Y$), it may also be desirable to examine the ambient air TSP levels contributed by each mode of transportataion. A modified version of equation 8 may be utilized for this purpose. The term E_Y is changed to the term E_{YX}, where X represents one mode of transportation (bus, taxi, HDT, orautomobile). In other words, equation 8 is used as if only one mode of transportation were responsible for the total emissions from the transportation sector. The equation must then be adjusted to remove all non-transportation contributions. The resulting equation is an expression for the ambient TSP contribution from one mode of transportation as follows:

$$(8a) \quad \bar{X}_{YX} = \frac{\bar{X}_B\left(E_{YX} + E_B(\frac{1 - p}{p})\right)}{E_B + E_B(\frac{1 - p}{p})} - (1 - p)(\bar{X}_B)$$

where

$\bar{X}_{YX}$ = the ambient TSP level contribution from mode of transportation X.

We now need to derive the term E_Y from base year data or from scenario data. The basic equation for calculating the normalized vehicle emissions for a given city in a given projection year is as follows:

$$(9) \qquad E_Y = E(a) + E(T) + E(b) + E(t)$$

where

E_Y = the total particulate emissions for a projection year Y,

$E(a)$ = the normalized particulate emission which is a function of the characteristics of automobiles and light duty trucks in year Y,

$E(T)$ = the normalized particulate emission which is a function of the characteristics of heavy duty trucks (HDT's) in year Y,

$E(b)$ = the normalized particulate emission which is a function of the characteristics of buses in year Y, and

$E(t)$ = the normalized particulate emission which is a function of the characteristics of taxis in year Y.

All emissions (E) are normalized to the base year 1976 and expressed as fractions of the 1976 emission rate. They may be considered as g/VMT (grams per vehicle-mile traveled) or as fractional grams emitted for a standard 1-mile unit of travel.

Each E(x) function in Equation 9 may be conceived as the product of a scenario-specific emission factor and a scenario-specific mode-of-transportation fraction (modal fraction). Thus, Equation 9 can be reexpressed as follows:

$$(10) \qquad E_Y = f_aE_a + f_TE_T + f_tE_t + f_bE_b$$

where each subscript refers to the modes of transportation indicated by those letters in Equation 9, and

where

f_x = the fractions of total VMT in 1976 that are projected to be traveled by transportation mode (x) in projection year Y under a given transportation scenario (T_1, T_2, ...etc.), and

E_x = a weighted emission factor which takes into account the various adjustments that have to be made under the diesel sales scenarios (D_1 or D_2).

The fractions f_x can be taken directly from tables in Chapter 2. However, the normalized modal choice fractions (f_x) can also be expressed in a "simple interest rate" formula, as follows:

$$f_x = V_{Bx} + r_{xs}^{(Y-B)} \qquad (11)$$

where

f_x = the modal choice fraction for transportation mode x in projection year Y,

V_{Bx} = the fraction of total VMT in base year B that were attributed to transportation mode x,

r_s = the annual rate of growth (expressed as a fraction) for transportation mode x under transportation scenario T_s (T_1, T_2,... etc.).

Y = the projection year of concern, and

B = base year 1976.

Each of the variables in Equation 11 is an input from a scenario or from basic input data; therefore the equation is in final form.

Next, an expression is needed to calculate each of the emission factors E_x in Equation 10. Each E_x is derived in a different manner. Let us first take E_a, which is a weighted emission factor that depends upon automobile age class travel fractions and the model-year emission factors for a given projection year, as follows:

$$E_a = \sum_{n=1}^{20} f_{an}E_{an} \tag{12}$$

where

E_a = a weighted emissions factor which takes into account the travel fractions and emission rates attributable to each of 20 age classes of vehicles on the road in projection year Y,

f_{an} = the travel fraction attributable to automobile age class n in projection year Y, and

E_{an} = the emission rate applicable to all automobiles of age class n in projection year Y.

However, E_{an} must take into account emissions from both diesel and gasoline automobiles, and these can assume different values under different scenarios. Instead of E_{an} we need to substitute a term which weights the diesel emissions and gasoline emissions according to fraction of that vehicle age class that was diesel when the vehicles were new. After substitution, we have the following:

$$E_a = \sum_{n=1}^{20} f_{an}F_{adm}E_{adm} + (1-F_{adm})E_{agm} \tag{13}$$

where E_a and f_{an} are defined as in Equation 12, and

F_{adm} = the fraction of automobile sales that were diesel for model year m (m = Y - n) under a given diesel sales scenario D_s,

E_{adm} = the emission rate for all diesel automobiles of model year m in projection year Y in a given emissions scenario E_s,

E_{agm} = the emission rate for all gasoline automobiles of model year m in projection year Y in a given emissions scenario E_s.

The emission rates E_{adm} and E_{agm} can be taken from tables in Chapter 4. The diesel sales fraction F_{adm} can be taken from tables in Chapter 3 or it can be derived from scenario input assumptions. If it is to be calculated, the cumulative logistic distribution formula applies, as follows:

$$(14) \qquad F_{adm}(Y) = \left[1 + \exp -\left(\frac{Y-\alpha}{\beta}\right)\right]^{-1}$$

where

$F_{adm}(Y)$ = the diesel sales fraction, a function of the projection year Y under a given diesel sales scenario D_s, and

α and β = dimensionless parameters which determine the shape of the described curve.

When two points (x,y) and (x_2, y_2) are given in a diesel sales scenario D_s, then the α and β parameters can be calculated, using the following equations from Appendix A:

$$(15) \qquad \beta = (x_1-x_2)\left\{\ln\left[\frac{F_{adm}(Y_1)}{1-F_{adm}(Y_1)}\right]-\ln\left[\frac{F_{adm}(Y_2)}{1-F_{adm}(Y_2)}\right]\right\}^{-1}$$

$$(16) \qquad \alpha = \left\{x_2\ln\left[\frac{F_{adm}(Y_1)}{1-F_{adm}(Y_1)}\right] - x_1\ln\left[\frac{F_{adm}(Y_2)}{1-F_{adm}(Y_2)}\right]\right\} \left\{\ln\left[\frac{F_{adm}(Y_1)}{1-F_{adm}(Y_1)}\right]-\ln\left[\frac{F_{adm}(Y_2)}{1-F_{adm}(Y_2)}\right]\right\}^{-1}$$

Equations 12 through 16 could be combined into one very large expression and substituted into Equation 10, but the result would be rather unwieldy. It is more effective to think of these as a series of steps.

Now let us return to the term E_T in Equation 10, which represents the emissions from heavy duty trucks. E_T must take into consideration the diesel and gasoline truck sales, and the different travel fractions and emissions from these types of vehicles, as well as the differences between vehicle age classes. The formula is as follows:

$$E_T = \sum_{n=1}^{20} f_{Tdn} E_{Tdn} + \sum_{n=1}^{20} (1-f_{Tdn}) E_{Tgn} \qquad (17)$$

where

E_T = total emissions from HDT in projection year Y,

f_{Tdn} = the diesel travel fraction for a vehicle age group n applicable to all projection years, expressed as a fraction of total HDT-VMT,

E_{Tdn} = the weighted emission rate applicable to diesel HDT's for vehicle age class n in projection year Y under emissions scenario E_s,

$1-f_{Tdn}$ = the gasoline travel fraction, and

E_{Tgn} = the weighted emission rate applicable to gasoline HDT's for vehicle age class n in projection year Y under emissions scenario E_s.

Since only one scenario is involved in HDT projected sales, the term f_{Tdn} may be considered fixed. The values given in Table D-3 may be substituted in the above equation. Values for E_{Tgn} depend only upon the model year of manufacture ($m = y-n$), and may be input from the emission factor scenarios (Table D-3). E_{Tdn} is taken to be 2.0g/VMT for all model years in all projection years, and therefore may be substituted directly into Equation 17.

It was found that taxis have the same distribution of diesel in the vehicle population as automobiles. Therefore, $E_a = E_t$ for any projection year, and the automobile emission factors can be used in solving Equation 10. Likewise, it was found that buses have about the same distribution of diesel in the vehicle population as HDT's. Therefore $E_b = E_t$ and this value can be substituted into Equation 10.

APPENDIX F - TABLES OF PROJECTED MEAN ANNUAL TSP AND BAP LEVELS

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TABLE F-1. PROJECTED MEAN ANNUAL TSP LEVELS ($\mu g/m^3$)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at 170 E. 121 St.					
1976	62.971	62.971	62.971	62.971	62.971	62.971
1977	63.105	63.062	62.929	63.104	63.061	62.926
1978	63.315	63.153	62.970	63.313	63.152	62.968
1979	62.359	62.176	61.803	62.369	62.185	61.813
1980	61.465	61.361	60.973	61.536	61.429	61.039
1981	60.940	60.834	60.353	61.018	60.907	60.425
1982	60.468	60.373	59.708	60.705	60.598	59.925
1983	60.143	60.061	59.304	60.641	60.535	59.757
1984	59.879	59.933	59.047	60.899	60.868	59.961
1985	59.865	59.801	58.847	61.514	61.357	60.307
1986	59.909	59.948	58.886	62.769	62.630	61.383
1987	59.955	60.001	58.831	64.406	64.157	62.664
1988	60.208	60.155	58.869	66.855	66.329	64.514
1989	60.210	60.259	58.864	69.236	68.593	66.439
1990	60.470	60.417	59.008	72.072	71.069	68.609
1991	60.575	60.629	59.005	74.669	73.506	70.516
1992	60.786	60.737	59.002	77.236	75.680	72.264
1993	60.840	60.792	59.060	79.583	77.723	73.958
1994	60.842	60.902	59.059	81.635	79.556	75.354
1995	61.055	61.008	59.056	83.403	80.964	76.341
1996	61.219	61.275	59.205	85.027	82.436	77.376
1997	61.434	61.381	59.203	86.126	83.183	77.784
1998	61.437	61.488	59.200	87.281	84.201	78.392
1999	61.709	61.652	59.243	88.345	84.907	78.745
2000	61.819	61.759	59.347	88.948	85.335	78.944
	New York at Pier 42, Morton St. and Hudson R.					
1976	72.270	72.270	72.270	72.270	72.270	72.270
1977	72.423	72.375	72.221	72.423	72.374	72.221
1978	72.665	72.479	72.269	72.663	72.477	72.267
1979	71.568	71.358	70.929	71.579	71.368	70.941
1980	70.541	70.423	69.978	70.623	70.500	70.053
1981	69.939	69.817	69.266	70.029	69.901	69.348
1982	69.598	69.288	68.525	69.670	69.546	68.775
1983	69.024	68.930	68.062	69.596	69.474	68.582
1984	68.721	68.749	67.767	69.892	69.856	68.816
1985	66.736	68.632	67.537	70.598	70.418	69.213
1986	68.756	68.801	67.581	72.038	71.878	70.444
1987	68.809	68.861	67.519	73.917	73.631	71.918
1988	69.099	69.039	67.562	76.727	76.123	74.041
1989	69.101	69.158	67.557	79.460	78.722	76.250
1990	69.399	69.339	67.722	82.715	81.569	78.741
1991	69.521	69.588	67.718	85.695	84.360	80.929
1992	69.763	69.706	67.715	88.642	86.856	82.935
1993	69.824	69.770	67.781	91.336	89.200	84.879
1994	69.827	69.895	67.780	93.690	91.305	86.481
1995	70.072	70.017	67.777	95.718	92.920	87.614
1996	70.259	70.324	67.948	97.583	94.609	88.803
1997	70.506	70.446	67.945	98.848	95.466	89.271
1998	70.509	70.568	67.942	100.170	96.635	89.969
1999	70.822	70.756	67.992	101.391	97.445	90.373
2000	70.947	70.879	68.111	102.079	97.936	90.632

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at 240 2nd Ave.					
1976	74.626	74.626	74.626	74.626	74.626	74.626
1977	74.784	74.734	74.576	74.784	74.733	74.575
1978	75.034	74.842	74.625	75.032	74.640	74.623
1979	73.901	73.684	73.241	73.913	73.695	73.253
1980	72.841	72.719	72.259	72.925	72.798	72.337
1981	72.219	72.093	71.524	72.312	72.180	71.608
1982	71.660	71.547	70.759	71.941	71.814	71.017
1983	71.274	71.178	70.281	71.664	71.739	70.817
1984	70.962	70.990	69.976	72.171	72.134	71.359
1985	70.946	70.870	69.739	72.899	72.713	71.469
1986	70.997	71.044	69.784	74.386	74.222	72.740
1987	71.052	71.106	69.720	76.327	76.031	74.262
1988	71.352	71.289	69.764	79.229	78.605	76.455
1989	71.353	71.413	69.759	82.050	81.289	78.736
1990	71.662	71.599	69.929	85.412	84.223	81.308
1991	71.787	71.850	69.925	88.489	87.110	83.567
1992	72.037	71.978	69.922	91.531	89.688	85.639
1993	72.101	72.044	69.991	94.313	92.108	87.647
1994	72.103	72.174	69.990	96.744	94.281	89.300
1995	72.356	72.300	69.987	98.839	95.949	90.470
1996	72.550	72.617	70.163	100.764	97.693	91.698
1997	72.805	72.742	70.160	102.066	98.578	92.181
1998	72.808	72.868	70.157	103.436	99.786	92.902
1999	73.131	73.062	70.209	104.696	100.622	93.319
2000	73.260	73.189	70.332	105.406	101.129	93.555
	New York at Central Park Arsenal, 5th Ave. and 64th St.					
1976	58.160	58.160	58.160	58.160	58.160	58.160
1977	58.283	58.244	58.121	58.283	58.243	58.120
1978	58.478	58.328	58.159	58.476	58.327	58.158
1979	57.595	57.426	57.081	57.604	57.434	57.093
1980	56.769	56.673	56.315	56.834	56.735	56.376
1981	56.284	56.186	55.742	56.356	56.254	55.808
1982	55.849	55.760	55.146	56.067	55.968	55.347
1983	55.548	55.472	54.773	56.008	55.910	55.192
1984	55.304	55.326	54.536	56.246	56.218	55.380
1985	55.292	55.233	54.351	56.814	56.669	55.700
1986	55.332	55.368	54.387	57.973	57.845	56.690
1987	55.374	55.417	54.337	59.486	59.255	57.877
1988	55.608	55.560	54.371	61.747	61.261	59.585
1989	55.610	55.656	54.367	63.946	63.352	61.363
1990	55.850	55.801	54.500	66.566	65.640	63.367
1991	55.947	55.997	54.497	68.964	67.890	65.129
1992	56.142	56.095	54.494	71.335	69.898	66.743
1993	56.192	56.148	54.547	73.503	71.785	68.308
1994	56.194	56.249	54.547	75.398	73.478	69.597
1995	56.391	56.347	54.544	77.031	74.778	70.508
1996	56.542	56.594	54.682	78.531	76.138	71.465
1997	56.740	56.692	54.679	79.546	76.827	71.841
1998	56.743	56.790	54.677	80.613	77.768	72.403
1999	56.995	56.941	54.717	81.595	78.420	72.728
2000	57.096	57.040	54.813	82.149	78.815	72.913

TABLE F-1. (CONTIUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at Stienman Hall, W. 141 St. and Convent Ave.					
1976	59.692	59.692	59.692	59.692	59.692	59.692
1977	59.819	59.778	59.652	59.818	59.778	59.651
1978	60.018	59.865	59.691	60.016	59.863	59.689
1979	59.112	58.939	58.584	59.121	58.947	58.594
1980	58.264	58.166	57.799	58.331	58.230	57.861
1981	57.767	57.666	57.211	57.841	57.735	57.278
1982	57.320	57.229	56.599	57.544	57.442	56.805
1983	57.011	56.934	56.216	57.483	57.383	56.645
1984	56.761	56.784	55.972	57.728	57.699	56.839
1985	56.748	56.697	55.783	58.311	58.162	57.167
1986	56.789	56.627	55.819	59.500	59.369	58.184
1987	56.833	56.876	55.768	61.053	60.816	59.401
1988	57.073	57.023	55.803	63.374	62.875	61.155
1989	57.074	57.122	55.799	65.630	65.021	62.980
1990	57.321	57.271	55.935	68.319	67.369	65.037
1991	57.421	57.472	55.932	70.781	69.678	66.844
1992	57.621	57.574	55.929	73.214	71.740	68.501
1993	57.672	57.627	55.984	75.439	73.676	70.107
1994	57.674	57.731	55.983	77.384	75.414	71.430
1995	57.876	57.831	55.981	79.060	76.748	72.366
1996	58.031	58.085	56.122	80.599	78.143	73.347
1997	58.235	58.185	56.120	81.641	78.851	73.734
1998	58.238	58.286	56.117	82.736	79.817	74.313
1999	58.496	58.441	56.159	83.744	80.486	74.644
2000	58.600	58.543	56.257	84.313	80.891	74.833

	Chicago at 3500 E. 114 St.					
1976	164.905	164.905	164.905	164.905	164.905	164.905
1977	165.202	165.108	164.718	165.199	165.105	164.717
1978	165.499	165.108	164.772	165.494	165.105	164.766
1979	162.360	161.920	161.530	162.401	161.962	161.567
1980	159.660	159.445	158.607	159.876	159.655	159.006
1981	157.742	157.296	156.645	157.988	157.536	156.869
1982	156.237	155.542	154.928	156.916	156.204	155.549
1983	154.672	154.249	153.420	156.062	155.592	154.672
1984	153.720	153.313	152.517	156.506	155.990	154.995
1985	153.297	152.901	151.871	157.757	157.168	155.783
1986	152.964	152.577	151.556	160.637	159.890	158.200
1987	152.695	152.314	151.301	164.579	163.584	161.433
1988	152.908	152.528	151.512	170.566	169.211	166.352
1989	153.120	152.465	151.172	177.045	174.935	170.975
1990	153.134	152.751	151.172	183.782	181.417	176.166
1991	153.349	152.688	151.382	190.485	187.256	181.183
1992	153.287	152.626	151.046	196.540	192.688	185.284
1993	153.148	152.493	150.920	202.281	197.823	189.228
1994	153.084	152.432	151.141	207.424	202.317	192.809
1995	153.646	152.710	150.854	211.929	206.012	194.929
1996	153.731	152.794	151.189	215.764	209.181	197.269
1997	153.735	152.783	150.899	217.895	210.826	197.822
1998	154.020	153.063	150.887	221.044	213.464	199.077
1999	154.109	153.138	151.226	223.195	214.916	200.035
2000	154.110	153.420	150.933	224.142	215.980	199.700

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Chicago at 1947 W. Polk					
1976	80.529	80.529	80.529	80.529	80.529	80.529
1977	80.674	80.628	80.438	80.673	80.627	80.437
1978	80.819	80.628	80.464	80.816	80.627	80.461
1979	79.286	79.071	78.881	79.306	79.092	78.899
1980	77.968	77.863	77.551	78.073	77.965	77.649
1981	77.031	76.813	76.495	77.151	76.930	76.605
1982	76.296	75.957	75.657	76.627	76.280	75.960
1983	75.532	75.325	74.921	76.210	75.981	75.532
1984	75.067	74.868	74.480	76.427	76.176	75.689
1985	74.860	74.667	74.164	77.039	76.751	76.070
1986	74.698	74.509	74.010	78.445	78.080	77.255
1987	74.567	74.380	73.886	80.370	79.884	78.834
1988	74.670	74.485	73.989	83.294	82.632	81.236
1989	74.774	74.454	73.823	86.457	85.427	83.493
1990	74.781	74.593	73.823	89.747	88.592	86.028
1991	74.886	74.563	73.925	93.021	91.444	88.478
1992	74.856	74.533	73.761	95.978	94.097	90.481
1993	74.788	74.468	73.700	98.781	96.604	92.407
1994	74.756	74.438	73.808	101.293	98.799	94.156
1995	75.031	74.574	73.667	103.493	100.603	95.191
1996	75.072	74.610	73.831	105.365	102.150	96.334
1997	75.075	74.609	73.689	106.406	102.954	96.603
1998	75.214	74.746	73.684	107.944	104.242	97.216
1999	75.257	74.783	73.849	108.994	104.951	97.684
2000	75.257	74.920	73.706	109.456	105.471	97.521

	Chicago at 9800 South Torrence Ave.					
1976	88.112	88.112	88.112	88.112	88.112	88.112
1977	88.271	88.221	88.012	88.269	88.219	88.011
1978	88.429	88.221	88.041	88.426	88.219	88.038
1979	86.752	86.517	86.309	86.774	86.540	86.328
1980	85.310	85.195	84.854	85.425	85.307	84.960
1981	84.285	84.046	83.698	84.416	84.174	83.818
1982	83.480	83.109	82.781	83.843	83.463	83.113
1983	82.644	82.418	81.975	83.387	83.136	82.645
1984	82.136	81.918	81.493	83.624	83.349	82.817
1985	81.910	81.698	81.148	84.293	83.978	83.238
1986	81.732	81.525	80.980	85.831	85.432	84.529
1987	81.588	81.384	80.843	87.938	87.406	86.257
1988	81.702	81.499	80.956	91.137	90.413	88.885
1989	81.815	81.465	80.774	94.598	93.471	91.355
1990	81.823	81.617	80.774	98.198	96.935	94.129
1991	81.937	81.580	80.886	101.780	100.055	96.809
1992	81.904	81.551	80.707	105.015	102.957	99.001
1993	81.830	81.480	80.640	108.083	105.701	101.108
1994	81.796	81.447	80.758	110.831	108.102	103.022
1995	82.096	81.596	80.604	113.238	110.076	104.154
1996	82.141	81.636	80.783	115.287	111.769	105.405
1997	82.144	81.635	80.628	116.425	112.648	105.700
1998	82.296	81.785	80.622	118.108	114.058	106.371
1999	82.343	81.825	80.803	119.257	114.834	106.883
2000	82.344	81.975	80.647	119.763	115.402	106.704

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination $T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Chicago at 538 S. Clark St.					
1976	83.719	83.719	83.719	83.719	83.719	83.719
1977	83.870	83.822	83.624	83.868	83.821	83.623
1978	84.020	83.822	83.652	84.018	83.821	83.649
1979	82.427	82.204	82.006	82.448	82.225	82.324
1980	81.056	80.948	80.623	81.166	81.054	80.724
1981	80.082	79.856	79.525	80.207	79.978	79.639
1982	79.318	78.966	78.654	79.663	79.302	78.969
1983	78.524	78.309	77.888	79.229	78.991	78.524
1984	78.041	77.834	77.430	79.455	79.193	78.688
1985	77.826	77.625	77.102	80.090	79.791	79.088
1986	77.657	77.460	76.942	81.552	81.173	80.315
1987	77.520	77.327	76.812	83.558	83.049	81.956
1988	77.628	77.436	76.919	86.593	85.905	84.454
1989	77.736	77.413	76.747	89.882	88.611	86.800
1990	77.743	77.548	76.747	93.302	92.102	89.436
1991	77.852	77.517	76.854	96.705	95.066	91.983
1992	77.821	77.485	76.683	99.780	97.624	94.065
1993	77.753	77.418	76.619	102.698	100.431	96.067
1994	77.718	77.387	76.731	105.305	102.713	97.886
1995	78.003	77.528	76.585	107.592	104.588	98.962
1996	78.046	77.565	76.756	109.539	106.187	100.150
1997	78.048	77.565	76.608	110.621	107.032	100.430
1998	76.193	77.707	76.602	112.223	108.371	101.067
1999	78.238	77.745	76.775	113.311	109.138	101.554
2000	78.239	77.888	76.626	113.792	109.649	101.384
	Chicago at 4015 North Ashland Ave.					
1976	69.040	69.040	69.040	69.040	69.040	69.040
1977	69.164	69.125	68.962	69.163	69.124	68.961
1978	69.289	69.125	68.984	69.286	69.124	68.982
1979	67.974	67.790	67.627	67.992	67.808	67.642
1980	66.844	66.755	66.487	66.935	66.842	66.570
1981	66.041	65.854	65.582	66.144	65.955	65.676
1982	65.411	65.123	64.863	65.695	65.397	65.123
1983	64.756	64.579	64.232	65.338	65.141	64.756
1984	64.357	64.187	63.854	65.524	65.308	64.891
1985	64.180	64.014	63.583	66.048	65.801	65.221
1986	64.041	63.879	63.451	67.253	66.940	66.233
1987	63.928	63.769	63.344	68.904	68.487	67.586
1988	64.017	63.858	63.433	71.410	70.843	69.646
1989	64.106	63.832	63.291	74.122	73.239	71.581
1990	64.112	63.951	63.290	76.943	75.953	73.755
1991	64.202	63.925	63.378	79.748	78.398	75.855
1992	64.176	63.899	63.238	82.285	80.672	77.572
1993	64.118	63.843	63.185	84.688	82.822	79.223
1994	64.091	63.818	63.278	86.841	84.703	80.723
1995	64.326	63.935	63.157	88.727	86.250	81.610
1996	64.362	63.965	63.298	90.333	87.577	82.590
1997	64.364	63.965	63.176	91.226	88.265	82.821
1998	64.483	64.082	63.171	92.543	89.370	83.347
1999	64.520	64.114	63.313	93.444	89.978	83.748
2000	64.520	64.232	63.191	93.840	90.423	83.608

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination $T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at 2300 Carson St., Torrence					
1976	83.489	83.489	83.489	83.489	83.489	83.489
1977	83.661	83.565	83.444	83.661	83.564	83.444
1978	83.833	83.641	83.476	83.833	83.639	83.474
1979	82.856	82.700	82.514	82.873	82.710	82.523
1980	82.081	81.913	81.558	82.155	81.977	81.621
1981	81.554	81.311	80.952	81.637	81.383	81.022
1982	81.079	80.849	80.492	81.319	81.061	80.694
1983	80.560	80.447	80.014	81.061	80.888	80.432
1984	80.349	80.264	79.835	81.368	81.155	80.672
1985	80.215	80.151	79.637	81.869	81.580	80.970
1986	80.307	80.165	79.560	83.185	82.625	81.836
1987	80.232	80.283	79.584	84.738	84.085	83.366
1988	80.335	80.396	79.689	87.099	86.038	84.808
1989	80.420	80.481	79.678	89.673	88.095	86.528
1990	80.448	80.605	79.700	92.412	90.325	88.373
1991	80.626	80.692	79.785	95.255	92.428	90.168
1992	80.709	80.781	79.870	97.900	94.399	91.816
1993	80.754	80.830	79.828	100.470	96.241	93.231
1994	80.740	80.920	79.916	102.734	97.899	94.555
1995	80.842	81.016	79.913	104.634	99.159	95.421
1996	81.078	81.152	79.946	106.586	100.369	96.229
1997	81.181	81.246	80.039	107.800	101.047	96.666
1998	81.186	81.440	80.132	109.221	102.044	97.281
1999	81.329	81.579	80.166	110.371	102.674	97.567
2000	81.528	81.675	80.163	111.304	103.038	97.625
	Los Angeles at 434 S. San Pedro St.					
1976	104.285	104.285	104.285	104.285	104.285	104.285
1977	104.500	104.380	104.229	104.500	104.379	104.229
1978	104.715	104.475	104.268	104.715	104.473	104.266
1979	103.497	103.300	103.067	103.515	103.312	103.079
1980	102.526	102.317	101.873	102.619	102.397	101.952
1981	101.868	101.565	101.116	101.972	101.654	101.203
1982	101.274	100.987	100.542	101.574	101.252	100.794
1983	100.626	100.485	99.944	101.253	101.036	100.466
1984	100.363	100.257	99.720	101.636	101.369	100.766
1985	100.196	100.115	99.473	102.261	101.901	101.139
1986	100.310	100.133	99.377	103.905	103.205	102.220
1987	100.217	100.280	99.408	105.845	105.029	103.756
1988	100.345	100.422	99.539	108.794	107.470	105.932
1989	100.452	100.528	99.524	112.009	110.038	108.081
1990	100.486	100.683	99.553	115.430	112.823	110.386
1991	100.708	100.792	99.658	118.982	115.451	112.627
1992	100.813	100.902	99.765	122.286	117.912	114.686
1993	100.868	100.964	99.712	125.495	120.213	116.453
1994	100.852	101.076	99.822	128.324	122.284	118.108
1995	100.978	101.195	99.818	130.697	123.858	119.189
1996	101.274	101.366	99.859	133.136	125.370	120.198
1997	101.402	101.486	99.975	134.651	126.217	120.744
1998	101.409	101.726	100.092	136.426	127.461	121.513
1999	101.587	101.899	100.134	137.863	128.249	121.869
2000	101.836	102.020	100.130	139.079	128.784	121.943

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination $T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at 2655 Pine Ave., Long Beach					
1976	86.336	86.336	86.336	86.336	86.336	86.336
1977	86.514	86.415	86.290	86.514	86.414	86.289
1978	86.692	86.493	86.322	86.692	86.491	86.320
1979	85.684	85.521	85.328	85.699	85.531	85.337
1980	84.880	84.736	84.339	84.956	84.773	84.405
1981	84.335	84.084	83.713	84.421	84.158	83.784
1982	83.843	83.606	83.237	84.092	83.825	83.446
1983	83.307	83.190	82.742	83.825	83.646	83.178
1984	83.089	83.001	82.557	84.143	83.922	83.423
1985	82.951	82.884	82.353	84.661	84.362	83.732
1986	83.045	82.899	82.273	86.021	85.442	84.627
1987	82.968	83.021	82.298	87.627	86.952	85.898
1988	83.074	83.138	82.407	90.069	88.972	87.700
1989	83.163	83.225	82.395	92.731	91.099	89.479
1990	83.191	83.354	82.418	95.563	93.405	91.387
1991	83.375	83.444	82.505	98.503	95.580	93.242
1992	83.461	83.535	82.594	101.239	97.618	94.947
1993	83.507	83.587	82.550	103.896	99.523	96.410
1994	83.494	83.679	82.641	106.238	101.237	97.779
1995	83.598	83.778	82.638	108.202	102.540	98.675
1996	83.843	83.919	82.672	110.221	103.792	99.510
1997	83.949	84.019	82.768	111.476	104.493	99.963
1998	83.955	84.217	82.865	112.945	105.523	100.599
1999	84.103	84.361	82.899	114.135	106.175	100.894
2000	84.309	84.461	82.897	115.100	106.552	100.954
	Los Angeles at 1196 East Walnut St., Pasedena					
1976	87.477	87.477	87.477	87.477	87.477	87.477
1977	87.657	87.557	87.430	87.657	87.556	87.430
1978	87.837	87.636	87.463	87.837	87.634	87.461
1979	86.816	86.651	86.456	86.831	86.661	86.465
1980	86.302	85.826	85.454	86.079	85.893	85.520
1981	85.450	85.195	84.819	85.537	85.270	84.892
1982	84.952	84.711	84.337	85.203	84.933	84.549
1983	84.408	84.290	83.836	84.933	84.751	84.278
1984	84.187	84.098	83.646	85.255	85.031	84.525
1985	84.047	83.979	83.441	85.779	85.477	84.838
1986	84.143	83.994	83.360	87.158	86.571	85.745
1987	84.064	84.118	83.386	88.785	88.101	87.033
1988	84.172	84.236	83.496	91.259	90.148	88.859
1989	84.262	84.325	83.484	93.956	92.303	90.661
1990	84.290	84.455	83.508	96.826	94.639	92.594
1991	84.477	84.547	83.596	99.805	96.843	94.475
1992	84.564	84.639	83.686	102.577	98.908	96.202
1993	84.611	84.691	83.641	105.269	100.838	97.684
1994	84.597	84.785	83.733	107.642	102.575	99.072
1995	84.703	84.885	83.730	109.632	103.895	99.979
1996	84.951	85.029	83.764	111.678	105.164	100.826
1997	85.058	85.129	83.862	112.949	105.874	101.284
1998	85.064	85.330	83.960	114.438	106.918	101.928
1999	85.214	85.476	83.995	115.643	107.578	102.227
2000	85.423	85.577	83.992	116.621	107.960	102.289

TABLE F-1. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at Keck Laboritories, California Institute of Technology. Pasedena					
1976	95.356	95.356	95.356	95.356	95.356	95.356
1977	95.552	95.443	95.305	95.552	95.442	95.304
1978	95.749	95.530	95.341	95.749	95.528	95.339
1979	94.636	94.455	94.243	94.652	94.467	94.253
1980	93.748	93.556	93.150	93.832	93.630	93.223
1981	93.146	92.868	92.458	93.241	92.950	92.538
1982	92.603	92.341	91.933	92.877	92.583	92.164
1983	92.011	91.881	91.387	92.583	92.385	91.860
1984	91.771	91.673	91.182	92.934	92.690	92.138
1985	91.617	91.543	90.956	93.506	93.176	92.479
1986	91.722	91.560	90.869	95.008	94.369	93.468
1987	91.636	91.694	90.896	96.782	96.036	94.872
1988	91.754	91.823	91.016	99.479	98.268	96.862
1989	91.851	91.920	91.003	102.419	100.617	98.827
1990	91.882	92.062	91.029	105.547	103.163	100.934
1991	92.086	92.162	91.125	108.794	105.566	102.984
1992	92.181	92.263	91.223	111.816	107.816	104.866
1993	92.232	92.319	91.174	114.750	109.920	106.483
1994	92.217	92.422	91.275	117.337	111.814	107.995
1995	92.332	92.531	91.272	119.507	113.253	108.984
1996	92.603	92.687	91.309	121.737	114.636	109.937
1997	92.720	92.797	91.415	123.122	115.410	110.406
1998	92.726	93.016	91.522	124.745	116.548	111.109
1999	92.889	93.174	91.560	126.050	117.268	111.435
2000	93.117	93.285	91.557	127.125	117.684	111.502

TABLE F-2. PROJECTED LEVELS OF BAP

(ng/m^3)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at 170 E. 121 St.					
1976	.45	.45	.45	.45	.45	.45
1977	.45	.45	.45	.45	.45	.45
1978	.46	.46	.45	.46	.46	.45
1979	.45	.45	.45	.45	.45	.45
1980	.44	.44	.44	.44	.44	.44
1981	.44	.44	.44	.44	.44	.44
1982	.44	.44	.43	.44	.44	.43
1983	.43	.43	.43	.44	.44	.43
1984	.43	.43	.43	.44	.44	.43
1985	.43	.43	.42	.44	.44	.43
1986	.43	.43	.42	.45	.45	.44
1987	.43	.43	.42	.46	.46	.45
1988	.43	.43	.42	.48	.48	.47
1989	.43	.43	.42	.50	.49	.48
1990	.44	.44	.43	.52	.51	.49
1991	.44	.44	.43	.54	.53	.51
1992	.44	.44	.43	.56	.55	.52
1993	.44	.44	.43	.57	.56	.53
1994	.44	.44	.43	.59	.57	.54
1995	.44	.44	.43	.60	.58	.55
1996	.44	.44	.43	.61	.59	.56
1997	.44	.44	.43	.62	.60	.56
1998	.44	.44	.43	.63	.61	.57
1999	.44	.44	.43	.64	.61	.57
2000	.45	.45	.43	.64	.62	.57
	New York at Pier 42, Morton St. and Hudson R.					
1976	.52	.52	.52	.52	.52	.52
1977	.52	.52	.52	.52	.52	.52
1978	.52	.52	.52	.52	.52	.52
1979	.52	.51	.51	.52	.51	.51
1980	.51	.51	.50	.51	.51	.51
1981	.50	.50	.50	.50	.50	.50
1982	.50	.50	.49	.50	.50	.50
1983	.50	.50	.49	.50	.50	.49
1984	.50	.50	.49	.50	.50	.50
1985	.50	.49	.49	.51	.51	.50
1986	.50	.50	.49	.52	.52	.51
1987	.50	.50	.49	.53	.53	.52
1988	.50	.50	.49	.55	.55	.53
1989	.50	.50	.49	.57	.57	.55
1990	.50	.50	.49	.60	.59	.57
1991	.50	.50	.49	.62	.61	.58
1992	.50	.50	.49	.64	.63	.60
1993	.50	.50	.49	.66	.64	.61
1994	.50	.50	.49	.68	.66	.62
1995	.51	.50	.49	.69	.67	.63
1996	.51	.51	.49	.70	.68	.64
1997	.51	.51	.49	.71	.69	.64
1998	.51	.51	.49	.72	.70	.65
1999	.51	.51	.49	.73	.70	.65
2000	.51	.51	.49	.74	.71	.65

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at 240 2nd Ave.					
1976	.54	.54	.54	.54	.54	.54
1977	.54	.54	.54	.54	.54	.54
1978	.54	.54	.54	.54	.54	.54
1979	.53	.53	.53	.53	.53	.53
1980	.53	.52	.52	.53	.52	.52
1981	.52	.52	.52	.52	.52	.52
1982	.52	.52	.51	.52	.52	.51
1983	.51	.51	.51	.52	.52	.51
1984	.51	.51	.50	.52	.52	.51
1985	.51	.51	.50	.53	.52	.52
1986	.51	.51	.50	.54	.54	.52
1987	.51	.51	.50	.55	.55	.54
1988	.51	.51	.50	.57	.57	.55
1989	.51	.51	.50	.59	.59	.57
1990	.52	.52	.50	.62	.61	.59
1991	.52	.52	.50	.64	.63	.60
1992	.52	.52	.50	.66	.65	.62
1993	.52	.52	.50	.68	.66	.63
1994	.52	.52	.50	.70	.68	.64
1995	.52	.52	.50	.71	.69	.65
1996	.52	.52	.51	.73	.70	.66
1997	.52	.52	.51	.74	.71	.66
1998	.52	.53	.51	.75	.72	.67
1999	.53	.53	.51	.75	.73	.67
2000	.53	.53	.51	.76	.73	.67
	New York at Central Park Arsenal, 5th Ave. and 64th St.					
1976	.42	.42	.42	.42	.42	.42
1977	.42	.42	.42	.42	.42	.42
1976	.42	.42	.42	.42	.42	.42
1979	.42	.41	.41	.42	.41	.41
1980	.41	.41	.41	.41	.41	.41
1981	.41	.41	.40	.41	.41	.40
1982	.40	.40	.40	.40	.40	.40
1983	.40	.40	.39	.40	.40	.40
1984	.40	.40	.39	.41	.41	.40
1985	.40	.40	.39	.41	.41	.40
1986	.40	.40	.39	.42	.42	.41
1987	.40	.40	.39	.43	.43	.42
1988	.40	.40	.39	.45	.44	.43
1989	.40	.40	.39	.46	.46	.44
1990	.40	.40	.39	.48	.47	.46
1991	.40	.40	.39	.50	.49	.47
1992	.40	.40	.39	.51	.50	.46
1993	.41	.40	.39	.53	.52	.49
1994	.41	.41	.39	.54	.53	.50
1995	.41	.41	.39	.56	.54	.51
1996	.41	.41	.39	.57	.55	.52
1997	.41	.41	.39	.57	.55	.52
1998	.41	.41	.39	.58	.56	.52
1999	.41	.41	.39	.59	.57	.52
2000	.41	.41	.40	.59	.57	.53

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	New York at Stienman Hall, W. 141 St. and Convent Ave.					
1976	.49	.49	.49	.49	.49	.49
1977	.49	.49	.49	.49	.49	.49
1978	.49	.49	.49	.49	.49	.49
1979	.49	.48	.48	.49	.48	.48
1980	.48	.48	.47	.48	.48	.47
1981	.47	.47	.47	.47	.47	.47
1982	.47	.47	.46	.47	.47	.47
1983	.47	.47	.46	.47	.47	.46
1984	.47	.47	.46	.47	.47	.47
1985	.47	.47	.46	.48	.48	.47
1986	.47	.47	.46	.49	.49	.48
1987	.47	.47	.46	.50	.50	.49
1988	.47	.47	.46	.52	.52	.50
1989	.47	.47	.46	.54	.53	.52
1990	.47	.47	.45	.56	.55	.53
1991	.47	.47	.46	.58	.57	.55
1992	.47	.47	.46	.60	.59	.56
1993	.47	.47	.46	.62	.60	.58
1994	.47	.47	.46	.64	.62	.59
1995	.48	.47	.46	.65	.63	.59
1996	.48	.48	.46	.66	.64	.60
1997	.48	.48	.46	.67	.65	.61
1998	.48	.48	.46	.68	.66	.61
1999	.48	.48	.46	.69	.66	.61
2000	.48	.48	.46	.69	.66	.61
	Chicago at 3500 E. 114 St.					
1976	.43	.43	.43	.43	.43	.43
1977	.43	.43	.43	.43	.43	.43
1978	.43	.43	.43	.43	.43	.43
1979	.43	.42	.42	.43	.43	.42
1980	.42	.42	.42	.42	.42	.42
1981	.42	.42	.41	.42	.42	.41
1982	.41	.41	.41	.41	.41	.41
1983	.41	.41	.41	.41	.41	.41
1984	.41	.41	.40	.42	.42	.41
1985	.41	.41	.40	.42	.42	.41
1986	.41	.41	.40	.43	.43	.42
1987	.41	.41	.40	.44	.44	.43
1988	.41	.41	.40	.46	.45	.44
1989	.41	.41	.40	.47	.47	.45
1990	.41	.41	.40	.49	.49	.47
1991	.41	.41	.40	.51	.50	.48
1992	.42	.42	.40	.53	.52	.49
1993	.42	.42	.40	.54	.53	.51
1994	.42	.42	.40	.56	.54	.52
1995	.42	.42	.40	.57	.55	.52
1996	.42	.42	.40	.58	.56	.53
1997	.42	.42	.40	.59	.57	.53
1998	.42	.42	.40	.60	.58	.54
1999	.42	.42	.40	.60	.58	.54
2000	.42	.42	.41	.61	.58	.54

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Chicago at 1947 W. Polk					
1976	.50	.50	.50	.50	.50	.50
1977	.50	.50	.50	.50	.50	.50
1978	.50	.50	.50	.50	.50	.50
1979	.49	.49	.49	.49	.49	.49
1980	.48	.46	.48	.48	.48	.46
1981	.48	.47	.47	.48	.48	.47
1982	.47	.47	.47	.47	.47	.47
1983	.47	.47	.46	.47	.47	.47
1984	.46	.46	.46	.47	.47	.47
1985	.46	.46	.46	.48	.47	.47
1986	.46	.46	.46	.48	.48	.48
1987	.46	.46	.46	.50	.49	.49
1988	.46	.46	.46	.51	.51	.50
1989	.46	.46	.46	.53	.53	.52
1990	.46	.46	.46	.55	.55	.53
1991	.46	.46	.46	.57	.57	.55
1992	.46	.46	.46	.59	.58	.56
1993	.46	.46	.46	.61	.60	.57
1994	.46	.46	.46	.63	.61	.58
1995	.46	.46	.46	.64	.62	.59
1996	.46	.46	.46	.65	.63	.60
1997	.46	.46	.46	.66	.64	.60
1998	.46	.46	.46	.67	.64	.60
1999	.47	.46	.46	.67	.65	.60
2000	.47	.46	.46	.68	.65	.60

	Chicago at 9800 South Torrence Ave.					
1976	.60	.60	.60	.60	.60	.60
1977	.60	.60	.60	.60	.60	.60
1978	.61	.60	.60	.61	.60	.60
1979	.59	.59	.59	.59	.59	.59
1980	.58	.58	.58	.59	.58	.58
1981	.58	.58	.57	.58	.58	.57
1982	.57	.57	.57	.57	.57	.57
1983	.57	.56	.56	.57	.57	.57
1984	.56	.56	.56	.57	.57	.57
1985	.56	.56	.56	.58	.58	.57
1986	.56	.56	.55	.59	.59	.58
1987	.56	.56	.55	.60	.60	.59
1988	.56	.56	.55	.62	.62	.61
1989	.56	.56	.55	.65	.64	.63
1990	.56	.56	.55	.67	.66	.64
1991	.56	.56	.55	.70	.69	.66
1992	.56	.56	.55	.72	.71	.68
1993	.56	.56	.55	.74	.72	.69
1994	.56	.56	.55	.76	.74	.71
1995	.56	.56	.55	.78	.75	.71
1996	.56	.56	.55	.79	.77	.72
1997	.56	.56	.55	.80	.77	.72
1998	.56	.56	.55	.81	.78	.73
1999	.56	.56	.55	.82	.79	.73
2000	.56	.56	.55	.82	.79	.73

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Chicago at 538 S. Clark St.					
1976	1.19	1.19	1.19	1.19	1.19	1.19
1977	1.19	1.19	1.19	1.19	1.19	1.19
1978	1.19	1.19	1.19	1.19	1.19	1.19
1979	1.17	1.17	1.16	1.17	1.17	1.16
1980	1.15	1.15	1.15	1.15	1.15	1.15
1981	1.14	1.13	1.13	1.14	1.14	1.13
1982	1.13	1.12	1.12	1.13	1.13	1.12
1983	1.12	1.11	1.11	1.13	1.12	1.12
1984	1.11	1.11	1.10	1.13	1.12	1.12
1985	1.11	1.10	1.09	1.14	1.13	1.12
1986	1.10	1.10	1.09	1.16	1.15	1.14
1987	1.10	1.10	1.09	1.19	1.18	1.16
1988	1.10	1.10	1.09	1.23	1.22	1.20
1989	1.10	1.10	1.09	1.28	1.26	1.23
1990	1.10	1.10	1.09	1.33	1.31	1.27
1991	1.11	1.10	1.09	1.37	1.35	1.31
1992	1.11	1.10	1.09	1.42	1.39	1.34
1993	1.10	1.10	1.09	1.46	1.43	1.36
1994	1.10	1.10	1.09	1.50	1.46	1.39
1995	1.11	1.10	1.09	1.53	1.49	1.41
1996	1.11	1.10	1.09	1.56	1.51	1.42
1997	1.11	1.10	1.09	1.57	1.52	1.43
1998	1.11	1.10	1.09	1.59	1.54	1.44
1999	1.11	1.10	1.09	1.61	1.55	1.44
2000	1.11	1.11	1.09	1.62	1.56	1.44
	Chicago at 4015 North Ashland Ave.					
1976	.64	.64	.64	.64	.64	.64
1977	.64	.64	.63	.64	.64	.63
1978	.64	.64	.63	.64	.64	.63
1979	.63	.62	.62	.63	.62	.62
1980	.62	.61	.61	.62	.62	.61
1981	.61	.61	.60	.61	.61	.60
1982	.60	.60	.60	.60	.60	.60
1983	.60	.59	.59	.60	.60	.60
1984	.59	.59	.59	.60	.60	.60
1985	.59	.59	.59	.61	.61	.60
1986	.59	.59	.58	.62	.62	.61
1987	.59	.59	.58	.63	.63	.62
1988	.59	.59	.58	.66	.65	.64
1989	.59	.59	.58	.68	.67	.66
1990	.59	.59	.58	.71	.70	.68
1991	.59	.59	.58	.73	.72	.70
1992	.59	.59	.58	.76	.74	.71
1993	.59	.59	.58	.78	.76	.73
1994	.59	.59	.58	.80	.78	.74
1995	.59	.59	.58	.82	.79	.75
1996	.59	.59	.58	.83	.81	.76
1997	.59	.59	.58	.84	.81	.76
1998	.59	.59	.58	.85	.82	.77
1999	.59	.59	.58	.86	.83	.77
2000	.59	.59	.58	.86	.83	.77

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at 2300 Carson St., Torrence					
1976	.58	.58	.58	.58	.58	.58
1977	.58	.56	.58	.58	.58	.58
1978	.58	.58	.58	.58	.58	.58
1979	.57	.57	.57	.57	.57	.57
1980	.56	.56	.56	.56	.56	.56
1981	.56	.55	.55	.56	.55	.55
1982	.55	.55	.55	.55	.55	.55
1983	.54	.54	.54	.55	.55	.54
1984	.54	.54	.54	.55	.55	.55
1985	.54	.54	.53	.56	.55	.55
1986	.54	.54	.53	.57	.56	.56
1987	.54	.54	.53	.58	.58	.57
1988	.54	.54	.53	.60	.60	.59
1989	.54	.54	.53	.62	.62	.60
1990	.54	.54	.53	.65	.64	.62
1991	.54	.54	.53	.67	.66	.64
1992	.54	.54	.53	.69	.68	.65
1993	.54	.54	.53	.71	.70	.67
1994	.54	.54	.53	.73	.71	.68
1995	.54	.54	.53	.75	.73	.69
1996	.54	.54	.53	.76	.74	.69
1997	.54	.54	.53	.77	.74	.70
1998	.54	.54	.53	.78	.75	.70
1999	.54	.54	.53	.79	.76	.70
2000	.54	.54	.53	.79	.76	.70
	Los Angeles at 434 S. San Pedro St.					
1976	.63	.63	.63	.63	.63	.63
1977	.63	.63	.63	.63	.63	.63
1978	.63	.63	.63	.63	.63	.63
1979	.63	.62	.62	.63	.62	.62
1980	.62	.62	.62	.62	.62	.62
1981	.62	.61	.61	.62	.61	.61
1982	.61	.61	.61	.61	.61	.61
1983	.61	.61	.60	.61	.61	.61
1984	.61	.61	.60	.61	.61	.61
1985	.61	.61	.60	.62	.62	.61
1986	.61	.61	.60	.63	.62	.62
1987	.61	.61	.60	.64	.64	.63
1988	.61	.61	.60	.66	.65	.64
1989	.61	.61	.60	.68	.67	.65
1990	.61	.61	.60	.70	.68	.67
1991	.61	.61	.60	.72	.70	.68
1992	.61	.61	.60	.74	.71	.69
1993	.61	.61	.60	.76	.73	.70
1994	.61	.61	.60	.78	.74	.71
1995	.61	.61	.60	.79	.75	.72
1996	.61	.61	.60	.81	.76	.73
1997	.61	.61	.60	.81	.76	.73
1998	.61	.62	.61	.83	.77	.73
1999	.61	.62	.61	.83	.78	.74
2000	.62	.62	.61	.84	.78	.74

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at 2655 Pine Ave., Long Beach					
1976	.75	.75	.75	.75	.75	.75
1977	.75	.75	.75	.75	.75	.75
1978	.75	.75	.75	.75	.75	.75
1979	.75	.74	.74	.75	.74	.74
1980	.74	.74	.73	.74	.74	.74
1981	.73	.73	.73	.74	.73	.73
1982	.73	.73	.72	.73	.73	.73
1983	.73	.72	.72	.73	.73	.72
1984	.72	.72	.72	.73	.73	.73
1985	.72	.72	.72	.74	.73	.73
1986	.72	.72	.72	.75	.74	.74
1987	.72	.72	.72	.76	.76	.75
1988	.72	.72	.72	.78	.77	.76
1989	.72	.72	.72	.81	.79	.78
1990	.72	.73	.72	.83	.81	.80
1991	.73	.73	.72	.86	.83	.81
1992	.73	.73	.72	.88	.85	.83
1993	.73	.73	.72	.90	.87	.84
1994	.73	.73	.72	.93	.88	.85
1995	.73	.73	.72	.94	.89	.86
1996	.73	.73	.72	.96	.90	.87
1997	.73	.73	.72	.97	.91	.87
1998	.73	.73	.72	.96	.92	.88
1999	.73	.73	.72	.99	.92	.88
2000	.73	.74	.72	1.00	.93	.88
	Los Angeles at 1196 East Walnut St., Pasedena					
1976	.60	.60	.60	.60	.60	.60
1977	.60	.60	.60	.60	.60	.60
1978	.60	.60	.60	.60	.60	.60
1979	.60	.60	.59	.60	.60	.59
1980	.59	.59	.59	.59	.59	.59
1981	.59	.59	.58	.59	.59	.58
1982	.58	.58	.58	.59	.58	.58
1983	.58	.56	.58	.58	.58	.58
1984	.58	.58	.58	.5[illegible]	.59	.58
1985	.58	.58	.57	.59	.59	.58
1986	.58	.58	.57	.60	.60	.59
1987	.58	.58	.57	.61	.61	.60
1988	.58	.58	.57	.63	.62	.61
1989	.58	.58	.57	.65	.64	.62
1990	.58	.58	.57	.67	.65	.64
1991	.58	.58	.58	.69	.67	.65
1992	.58	.58	.58	.71	.68	.66
1993	.58	.56	.58	.72	.69	.67
1994	.58	.58	.58	.74	.71	.68
1995	.58	.56	.58	.75	.71	.69
1996	.58	.59	.58	.77	.72	.69
1997	.59	.59	.58	.78	.73	.70
1998	.59	.59	.58	.79	.74	.70
1999	.59	.59	.58	.80	.74	.70
2000	.59	.59	.58	.80	.74	.70

TABLE F-2. (CONTINUED)

Projection Year	Scenario Combination					
	$T_1D_1E_1$	$T_2D_1E_1$	$T_3D_1E_1$	$T_1D_2E_1$	$T_2D_2E_1$	$T_3D_2E_1$
	Los Angeles at Keck Laboritories, California Institute of Technology, Pasedena					
1976	.69	.69	.69	.69	.69	.69
1977	.69	.69	.69	.69	.69	.69
1978	.69	.69	.69	.69	.69	.69
1979	.68	.68	.69	.68	.68	.68
1980	.68	.67	.67	.68	.68	.67
1981	.67	.67	.67	.67	.67	.67
1982	.67	.67	.66	.67	.67	.66
1983	.66	.66	.66	.67	.67	.66
1984	.66	.66	.66	.67	.67	.66
1985	.66	.66	.66	.67	.67	.67
1986	.66	.66	.66	.69	.68	.67
1987	.66	.66	.66	.70	.69	.68
1988	.66	.66	.66	.72	.71	.70
1989	.66	.66	.66	.74	.73	.71
1990	.66	.66	.66	.76	.74	.73
1991	.66	.66	.66	.76	.76	.74
1992	.66	.67	.66	.81	.78	.76
1993	.66	.67	.66	.83	.79	.77
1994	.66	.67	.66	.85	.81	.78
1995	.67	.67	.66	.86	.82	.79
1996	.67	.67	.66	.88	.83	.79
1997	.67	.67	.66	.89	.83	.80
1998	.67	.67	.66	.90	.84	.80
1999	.67	.67	.66	.91	.85	.80
2000	.67	.67	.66	.92	.85	.80
	Los Angeles at 11408 La Cienega Blvd., Lennox					
1976	.62	.62	.62	.62	.62	.62
1977	.62	.62	.62	.62	.62	.62
1978	.63	.62	.62	.63	.62	.62
1979	.62	.62	.62	.62	.62	.62
1980	.61	.61	.61	.61	.61	.61
1981	.61	.61	.60	.61	.61	.60
1982	.60	.60	.60	.61	.60	.60
1983	.60	.60	.60	.60	.60	.60
1984	.60	.60	.60	.61	.61	.60
1985	.60	.60	.59	.61	.61	.60
1986	.60	.60	.59	.62	.62	.61
1987	.60	.60	.59	.63	.63	.62
1988	.60	.60	.59	.65	.64	.63
1989	.60	.60	.59	.67	.66	.65
1990	.60	.60	.59	.69	.67	.66
1991	.60	.60	.59	.71	.69	.67
1992	.60	.60	.60	.73	.70	.68
1993	.60	.60	.60	.75	.72	.70
1994	.60	.60	.60	.77	.73	.70
1995	.60	.60	.60	.78	.74	.71
1996	.60	.61	.60	.79	.75	.72
1997	.61	.61	.60	.80	.75	.72
1998	.61	.61	.60	.81	.76	.73
1999	.61	.61	.60	.82	.77	.73
2000	.61	.61	.60	.83	.77	.73

APPENDIX G. PROJECTED TSP LEVELS ASSOCIATED WITH POPULATIONS AT RISK

TABLE G-1. PROJECTED TSP LEVESL ASSOCIATED WITH GIVEN FRACTIONS OF THE CHICAGO CENTRAL AREA POPULATION ($\mu g/m^3$)

Projection Year	Fraction of Population Exposed to Given TSP Levels or Higher		
	0.12	0.49	1.00
	Scenario $T_1D_1E_1$		
1980	81.1	78.0	66.8
1985	77.8	74.9	64.2
1990	77.7	74.8	64.1
1995	78.0	75.0	64.3
2000	78.2	75.3	64.5
	Scenario $T_1D_2E_1$		
1980	81.1	78.1	66.9
1985	80.1	77.0	66.0
1990	93.3	89.7	76.9
1995	107.6	103.5	88.7
2000	113.8	109.5	93.8
	Scenario $T_2D_2E_1$		
1980	81.1	78.0	66.8
1985	79.8	76.8	65.8
1990	92.1	88.6	75.9
1995	104.6	100.6	86.3
2000	109.6	105.5	90.4
	Scenario $T_3D_2E_1$		
1980	80.7	77.6	66.6
1985	79.1	76.1	65.2
1990	89.4	86.0	73.8
1995	99.0	95.2	81.6
2000	101.4	97.5	83.6

TABLE G-2. PROJECTED TSP LEVELS ASSOCIATED WITH GIVEN FRACTIONS OF THE MANHATTAN RESIDENT POPULATION ($\mu g/m^3$)

Projection Year	Fraction of Population Exposed to Given TSP Levels or Higher				
	.193	.436	.750	.952	.999
	Scenario $T_1D_1E_1$				
1980	72.8	70.5	61.5	58.3	56.8
1985	70.9	68.7	60.0	56.7	55.3
1990	71.7	69.4	60.5	57.3	55.9
1995	72.4	70.1	61.1	57.9	56.4
2000	73.3	71.0	61.8	58.6	57.1
	Scenario $T_1D_2E_1$				
1980	72.9	70.6	61.4	58.3	56.8
1985	72.9	70.6	61.5	58.3	56.8
1990	85.4	82.7	72.1	68.3	66.6
1995	98.8	95.7	83.4	79.1	77.0
2000	105.4	102.1	88.9	84.3	82.1
	Scenario $T_2D_2E_1$				
1980	72.8	70.5	61.4	58.2	56.7
1985	72.7	70.4	61.4	58.2	56.7
1990	84.2	81.6	71.1	67.4	65.6
1995	95.9	92.9	81.0	76.7	74.8
2000	101.1	97.9	85.3	80.9	78.8
	Scenario $T_3D_2E_1$				
1980	72.3	70.1	61.0	57.9	56.4
1985	71.5	69.2	60.3	57.2	55.7
1990	81.3	78.7	68.6	65.0	63.4
1995	90.5	87.6	76.3	72.4	70.5
2000	93.6	90.6	78.9	74.8	72.9

APPENDIX H. PROJECTED TSP CONTRIBUTIONS FROM FOUR MODES OF TRANSPORTATION

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Table H-1. PROJECTED TSP CONTRIBUTIONS FROM FOUR MODES OF TRANSPORTATION TO THE MONITORING SITE AT 240 2ND AVE., NEW YORK CITY

Projection Year	Bus	Taxi	Auto	HDT	Totals
			Scenario $T_1D_1E_1$		
1976	1.833	1.484	5.977	5.884	15.177
1977	1.929	1.500	6.017	5.884	15.330
1978	2.025	1.508	6.058	5.980	15.571
1979	2.190	1.218	4.897	6.170	14.475
1980	2.244	.970	3.912	6.323	13.448
1981	2.402	.770	3.094	6.580	12.846
1982	2.565	.598	2.406	6.734	12.305
1983	2.718	.448	1.805	6.959	11.931
1984	2.780	.344	1.388	7.117	11.628
1985	2.923	.274	1.108	7.308	11.613
1986	3.085	.229	.921	7.427	11.662
1987	3.234	.194	.780	7.507	11.715
1988	3.403	.170	.688	7.744	12.006
1989	3.421	.159	.643	7.785	12.007
1990	3.575	.148	.597	7.985	12.306
1991	3.714	.137	.551	8.026	12.427
1992	3.853	.125	.504	8.188	12.670
1993	3.974	.113	.457	8.188	12.731
1994	3.994	.101	.408	8.230	12.733
1995	4.115	.102	.411	8.351	12.978
1996	4.257	.102	.413	8.393	13.166
1997	4.379	.103	.416	8.515	13.413
1998	4.379	.103	.419	8.515	13.416
1999	4.523	.104	.421	8.680	13.729
2000	4.646	.105	.424	8.680	13.854
			Scenario $T_2D_1E_1$		
1976	1.833	1.484	5.977	5.884	15.177
1977	1.929	1.492	5.977	5.884	15.281
1978	2.025	1.500	5.977	5.884	15.386
1979	2.190	1.205	4.799	6.071	14.265
1980	2.346	.960	3.803	6.221	13.329
1981	2.507	.754	2.988	6.475	12.724
1982	2.672	.586	2.309	6.628	12.195
1983	2.936	.439	1.721	6.742	11.837
1984	3.113	.335	1.313	6.894	11.656
1985	3.260	.267	1.041	6.970	11.539
1986	3.428	.221	.860	7.199	11.708
1987	3.580	.187	.724	7.276	11.768
1988	3.755	.164	.634	7.392	11.945
1989	3.892	.153	.589	7.431	12.065
1990	4.052	.142	.543	7.508	12.246
1991	4.193	.130	.498	7.667	12.488
1992	4.335	.119	.453	7.706	12.612
1993	4.455	.107	.407	7.706	12.676
1994	4.599	.095	.362	7.746	12.802
1995	4.720	.096	.362	7.746	12.924

(Continued)

Table H-1. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Totals
	Scenario $T_2D_1E_1$ (Continued)				
1996	4.866	.096	.362	7.907	13.231
1997	4.987	.096	.362	7.907	13.352
1998	5.109	.097	.362	7.907	13.474
1999	5.257	.097	.362	7.947	13.662
2000	5.379	.097	.362	7.947	13.785
	Scenario $T_3D_1E_1$				
1976	1.833	1.484	5.977	5.884	15.177
1977	1.929	1.476	5.936	5.787	15.128
1978	2.025	1.468	5.895	5.787	15.176
1979	2.090	1.172	4.702	5.872	13.836
1980	2.244	.924	3.700	6.017	12.884
1981	2.402	.722	2.887	6.162	12.173
1982	2.459	.555	2.218	6.200	11.431
1983	2.610	.411	1.641	6.307	10.969
1984	2.780	.312	1.244	6.338	10.673
1985	2.811	.246	.979	6.408	10.444
1986	2.971	.201	.803	6.513	10.488
1987	3.118	.168	.671	6.468	10.426
1988	3.168	.146	.583	6.571	10.469
1989	3.303	.135	.538	6.487	10.463
1990	3.456	.124	.493	6.555	10.628
1991	3.474	.113	.449	6.589	10.624
1992	3.612	.102	.405	6.502	10.621
1993	3.733	.091	.362	6.502	10.688
1994	3.873	.081	.319	6.414	10.687
1995	3.873	.080	.317	6.414	10.684
1996	4.014	.079	.315	6.447	10.855
1997	4.136	.079	.312	6.325	10.852
1998	4.136	.078	.310	6.325	10.849
1999	4.279	.078	.307	6.235	10.899
2000	4.401	.077	.305	6.235	11.018
	Scenario $T_1D_2E_1$				
1976	1.812	1.501	6.045	5.819	15.177
1977	1.908	1.517	6.086	5.819	15.329
1978	2.003	1.526	6.127	5.914	15.569
1979	2.165	1.238	4.980	6.102	14.486
1980	2.219	1.005	4.053	6.253	13.529
1981	2.376	.806	3.245	6.507	12.935
1982	2.537	.673	2.706	6.660	12.576
1983	2.688	.583	2.348	6.882	12.502
1984	2.749	.598	2.414	7.038	12.799
1985	2.891	.672	2.715	7.227	13.504
1986	3.051	.905	3.643	7.345	14.945
1987	3.198	1.233	4.969	7.424	16.824

(Continued)

Table H-1. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Totals
	Scenario $T_1D_2E_1$ (Continued)				
1988	3.365	1.708	6.902	7.659	19.634
1989	3.383	2.237	9.048	7.699	22.366
1990	3.536	2.821	11.368	7.897	25.622
1991	3.673	3.375	13.617	7.938	28.602
1992	3.811	3.897	15.743	8.097	31.548
1993	3.930	4.400	17.815	8.097	34.242
1994	3.950	4.869	19.640	8.139	36.597
1995	4.069	5.219	21.078	8.258	38.626
1996	4.210	5.548	22.431	8.300	40.489
1997	4.331	5.739	23.260	8.421	41.751
1998	4.331	5.997	24.329	8.421	43.077
1999	4.473	6.195	25.044	8.584	44.297
2000	4.594	6.302	25.505	8.584	44.985
	Scenario $T_2D_2E_1$				
1976	1.812	1.501	6.045	5.819	15.177
1977	1.908	1.509	6.045	5.819	15.280
1978	2.003	1.517	6.045	5.819	15.384
1979	2.165	1.225	4.881	6.004	14.275
1980	2.320	.994	3.940	6.152	13.407
1981	2.479	.791	3.134	6.404	12.808
1982	2.643	.659	2.597	6.554	12.453
1983	2.903	.571	2.239	6.667	12.381
1984	3.079	.583	2.284	6.818	12.763
1985	3.224	.655	2.552	6.893	13.324
1986	3.390	.873	3.403	7.119	14.785
1987	3.541	1.189	4.612	7.196	16.538
1988	3.713	1.648	6.358	7.311	19.030
1989	3.849	2.147	8.284	7.349	21.629
1990	4.007	2.695	10.343	7.426	24.471
1991	4.147	3.225	12.314	7.582	27.267
1992	4.287	3.705	14.149	7.621	29.763
1993	4.406	4.184	15.896	7.621	32.107
1994	4.548	4.585	17.418	7.660	34.211
1995	4.668	4.917	18.582	7.660	35.827
1996	4.812	5.228	19.657	7.819	37.516
1997	4.932	5.382	20.239	7.819	38.373
1998	5.052	5.625	21.045	7.819	39.542
1999	5.199	5.757	21.538	7.859	40.352
2000	5.320	5.858	21.806	7.859	40.843

(Continued)

Table H-1. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Totals
	Scenario $T_3D_2E_1$				
1976	1.812	1.501	6.045	5.819	15.177
1977	1.908	1.493	6.004	5.723	15.127
1978	2.003	1.485	5.963	5.723	15.174
1979	2.067	1.192	4.781	5.807	13.847
1980	2.219	.957	3.833	5.950	12.960
1981	2.376	.757	3.028	6.094	12.256
1982	2.431	.624	2.495	6.131	11.681
1983	2.581	.535	2.136	6.237	11.488
1984	2.749	.542	2.163	6.268	11.722
1985	2.780	.603	2.400	6.337	12.119
1986	2.938	.794	3.177	6.441	13.350
1987	3.084	1.070	4.274	6.396	14.824
1988	3.133	1.467	5.849	6.498	16.947
1989	3.266	1.900	7.576	6.416	19.157
1990	3.418	2.358	9.389	6.483	21.648
1991	3.436	2.790	11.094	6.516	23.836
1992	3.572	3.187	12.652	6.430	25.842
1993	3.691	3.559	14.106	6.430	27.786
1994	3.830	3.876	15.338	6.343	29.388
1995	3.830	4.110	16.237	6.343	30.521
1996	3.970	4.294	17.070	6.376	31.709
1997	4.090	4.394	17.438	6.255	32.177
1998	4.090	4.540	17.990	6.255	32.875
1999	4.232	4.617	18.265	6.166	33.280
2000	4.353	4.645	18.344	6.166	33.508

Table H-3. PROJECTED TSP CONTRIBUTIONS FROM FOUR MODES OF TRANSPORTATION TO THE MONITORING SITE AT 434 S. SAN PEDRO St., LA

Projection Year	Bus	Taxi	Auto	HDT	Total
			Scenario $T_1D_1E_1$		
1976	2.090	.080	7.397	3.990	13.557
1977	2.185	.080	7.517	3.990	13.772
1978	2.280	.080	7.636	3.990	13.987
1979	2.353	.064	6.235	4.117	12.769
1980	2.511	.051	5.017	4.219	11.798
1981	2.675	.040	4.002	4.424	11.140
1982	2.843	.034	3.142	4.528	10.546
1983	2.892	.025	2.375	4.606	9.898
1984	3.067	.019	1.839	4.710	9.635
1985	3.211	.015	1.480	4.762	9.468
1986	3.377	.013	1.241	4.952	9.582
1987	3.413	.011	1.059	5.006	9.489
1988	3.583	.009	.940	5.086	9.617
1989	3.718	.009	.885	5.112	9.724
1990	3.757	.008	.828	5.165	9.758
1991	3.894	.007	.769	5.310	9.980
1992	4.033	.007	.708	5.337	10.085
1993	4.151	.006	.646	5.337	10.140
1994	4.172	.005	.581	5.365	10.124
1995	4.292	.005	.589	5.365	10.250
1996	4.433	.005	.596	5.512	10.546
1997	4.553	.005	.604	5.512	10.674
1998	4.553	.005	.611	5.512	10.681
1999	4.696	.005	.618	5.539	10.859
2000	4.817	.005	.626	5.660	11.108
			Scenario $T_2D_1E_1$		
1976	2.090	.080	7.397	3.990	13.557
1977	2.185	.080	7.397	3.990	13.652
1978	2.280	.080	7.397	3.990	13.747
1979	2.451	.064	5.940	4.117	12.572
1980	2.612	.051	4.707	4.219	11.589
1981	2.778	.040	3.698	4.321	10.837
1982	2.948	.031	2.858	4.422	10.259
1983	3.106	.023	2.129	4.499	9.757
1984	3.286	.018	1.625	4.600	9.529
1985	3.433	.014	1.289	4.651	9.387
1986	3.602	.011	1.065	4.727	9.405
1987	3.754	.010	.897	4.892	9.552
1988	3.930	.009	.785	4.970	9.694
1989	4.067	.009	.728	4.996	9.800
1990	4.226	.008	.672	5.048	9.955
1991	4.366	.007	.616	5.074	10.064
1992	4.507	.007	.560	5.100	10.174
1993	4.626	.006	.504	5.100	10.236
1994	4.768	.005	.448	5.126	10.348

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Table H-2. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
	Scenario $T_2D_1E_1$ (Continued)				
1995	4.888	.005	.448	5.126	10.467
1996	5.032	.005	.448	5.152	10.638
1997	5.152	.005	.448	5.152	10.758
1998	5.272	.005	.448	5.272	10.998
1999	5.419	.005	.448	5.299	11.171
2000	5.539	.005	.448	5.299	11.292
	Scenario $T_3D_1E_1$				
1976	2.090	.080	7.397	3.990	13.557
1977	2.185	.080	7.341	3.895	13.501
1978	2.280	.080	7.285	3.895	13.540
1979	2.451	.064	5.805	4.019	12.339
1980	2.511	.051	4.565	4.018	11.145
1981	2.675	.040	3.559	4.115	10.388
1982	2.843	.031	2.728	4.212	9.814
1983	2.999	.023	2.017	4.177	9.216
1984	3.176	.018	1.527	4.272	8.992
1985	3.211	.014	1.201	4.319	8.745
1986	3.377	.011	.984	4.277	8.649
1987	3.527	.009	.821	4.323	8.680
1988	3.699	.008	.712	4.392	8.811
1989	3.834	.007	.656	4.299	8.796
1990	3.874	.007	.601	4.344	8.825
1991	4.012	.006	.546	4.366	8.930
1992	4.151	.005	.492	4.388	9.037
1993	4.270	.005	.439	4.270	8.984
1994	4.411	.004	.387	4.292	9.094
1995	4.411	.004	.383	4.292	9.090
1996	4.553	.004	.380	4.194	9.131
1997	4.673	.004	.377	4.194	9.247
1998	4.793	.004	.373	4.194	9.364
1999	4.937	.004	.370	4.094	9.406
2000	4.937	.004	.366	4.094	9.403
	Scenario $T_1D_2E_1$				
1976	2.064	.081	7.471	3.941	13.557
1977	2.158	.081	7.592	3.941	13.772
1978	2.252	.081	7.713	3.941	13.987
1979	2.324	.065	6.332	4.066	12.787
1980	2.480	.053	5.191	4.167	11.891
1981	2.642	.042	4.192	4.369	11.244
1982	2.808	.038	3.529	4.472	10.846
1983	2.856	.033	3.087	4.549	10.525
1984	3.029	.034	3.194	4.651	10.908
1985	3.172	.037	3.621	4.703	11.533
1986	3.335	.050	4.901	4.891	13.177
1987	3.371	.068	6.734	4.944	15.117

Table H-2. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
			Scenario $T_1D_2E_1$ (Continued)		
1988	3.539	.093	9.412	5.023	18.066
1989	3.672	.122	12.439	5.049	21.281
1990	3.710	.152	15.738	5.102	24.702
1991	3.846	.181	18.983	5.244	28.254
1992	3.983	.208	22.096	5.271	31.558
1993	4.100	.233	25.163	5.271	34.767
1994	4.121	.256	27.921	5.298	37.596
1995	4.239	.273	30.160	5.298	39.969
1996	4.378	.289	32.297	5.443	42.408
1997	4.497	.297	33.686	5.443	43.923
1998	4.497	.309	35.449	5.443	45.698
1999	4.636	.316	36.710	5.471	47.135
2000	4.757	.320	37.633	5.590	48.301
			Scenario $T_2D_2E_1$		
1976	2.064	.081	7.471	3.941	13.557
1977	2.158	.081	7.471	3.941	13.651
1978	2.252	.081	7.471	3.941	13.745
1979	2.420	.065	6.032	4.066	12.584
1980	2.579	.053	4.870	4.167	11.669
1981	2.743	.042	3.874	4.267	10.926
1982	2.912	.035	3.210	4.368	10.524
1983	3.068	.030	2.767	4.443	10.308
1984	3.245	.030	2.822	4.543	10.641
1985	3.390	.034	3.155	4.594	11.173
1986	3.557	.045	4.206	4.669	12.477
1987	3.708	.062	5.700	4.831	14.301
1988	3.881	.093	7.859	4.908	16.742
1989	4.016	.122	10.238	4.934	19.310
1990	4.174	.152	12.784	4.986	22.095
1991	4.312	.181	15.219	5.011	24.723
1992	4.451	.208	17.488	5.037	27.184
1993	4.568	.233	19.646	5.037	29.485
1994	4.709	.256	21.528	5.063	31.556
1995	4.827	.273	22.967	5.063	33.130
1996	4.970	.289	24.295	5.088	34.642
1997	5.088	.297	25.015	5.088	35.489
1998	5.207	.309	26.011	5.207	36.733
1999	5.352	.316	26.620	5.233	37.521
2000	5.471	.320	26.952	5.233	37.976
			Scenario $T_3D_2E_1$		
1976	2.064	.081	7.471	3.941	13.557
1977	2.158	.081	7.415	3.847	13.501
1978	2.252	.081	7.358	3.847	13.538
1979	2.420	.065	5.895	3.970	12.351
1980	2.480	.053	4.723	3.968	11.224

Table H-2. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
	Scenario $T_3D_2E_1$ (Continued)				
1981	2.642	.042	3.728	4.064	10.475
1982	2.808	.035	3.064	4.160	10.066
1983	2.962	.030	2.621	4.126	9.738
1984	3.137	.030	2.652	4.219	10.038
1985	3.172	.034	2.940	4.265	10.411
1986	3.335	.045	3.888	4.224	11.493
1987	3.483	.055	5.220	4.270	13.028
1988	3.653	.076	7.137	4.338	15.204
1989	3.787	.100	9.221	4.246	17.353
1990	3.826	.124	11.417	4.290	19.658
1991	3.962	.148	13.477	4.312	21.899
1992	4.100	.170	15.354	4.334	23.958
1993	4.217	.191	17.101	4.217	25.725
1994	4.356	.209	18.576	4.239	27.380
1995	4.356	.223	19.643	4.239	28.461
1996	4.497	.236	20.596	4.142	29.470
1997	4.615	.243	21.017	4.142	30.017
1998	4.733	.253	21.657	4.142	30.785
1999	4.876	.259	21.963	4.044	31.141
2000	4.876	.262	22.033	4.044	31.215

Table H-3. PROJECTED TSP CONTRIBUTIONS FROM FOUR MODES OF TRANSPORTATION TO THE MONITORING SITE AT 538 S. CLARK ST., CHICAGO

Projection Year	Bus	Taxi	Auto	HDT	Total
	Scenario $T_1D_1E_1$				
1976	1.353	2.778	6.267	3.834	14.232
1977	1.353	2.787	6.295	3.947	14.383
1978	1.466	2.797	6.324	3.947	14.534
1979	1.513	2.254	5.101	4.073	12.940
1980	1.550	1.792	4.054	4.173	11.569
1981	1.709	1.413	3.200	4.274	10.596
1982	1.750	1.099	2.484	4.499	9.831
1983	1.780	.822	1.859	4.577	9.037
1984	1.820	.629	1.425	4.680	8.554
1985	1.972	.501	1.135	4.732	8.339
1986	2.004	.415	.942	4.809	8.170
1987	2.025	.351	.796	4.861	8.034
1988	2.195	.308	.700	4.939	8.141
1989	2.207	.288	.653	5.103	8.249
1990	2.229	.266	.605	5.156	8.257
1991	2.381	.245	.557	5.182	8.365
1992	2.393	.223	.509	5.209	8.334
1993	2.393	.202	.460	5.209	8.263
1994	2.405	.180	.410	5.235	8.231
1995	2.547	.180	.412	5.377	8.516
1996	2.560	.182	.414	5.404	8.559
1997	2.560	.182	.415	5.404	8.562
1998	2.702	.183	.417	5.404	8.706
1999	2.716	.183	.421	5.432	8.751
2000	2.716	.184	.421	5.432	8.752
	Scenario $T_2D_1E_1$				
1976	1.353	2.778	6.267	3.834	14.232
1977	1.353	2.768	6.267	3.947	14.336
1978	1.466	2.768	6.267	3.834	14.336
1979	1.513	2.216	5.033	3.956	12.717
1980	1.669	1.750	3.988	4.054	11.461
1981	1.709	1.375	3.133	4.152	10.369
1982	1.750	1.059	2.421	4.249	9.479
1983	1.907	.789	1.804	4.323	8.822
1984	1.950	.600	1.377	4.420	8.347
1985	2.103	.474	1.092	4.469	8.138
1986	2.138	.392	.902	4.542	7.974
1987	2.161	.329	.760	4.591	7.840
1988	2.332	.285	.665	4.664	7.949
1989	2.344	.266	.617	4.689	7.917
1990	2.508	.246	.570	4.738	8.061
1991	2.521	.224	.522	4.762	8.030
1992	2.534	.203	.475	4.786	7.999
1993	2.675	.183	.427	4.646	7.931
1994	2.688	.162	.380	4.669	7.900
1995	2.830	.162	.380	4.669	8.041

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Table H-3. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
	Scenario $T_2D_1E_1$ (Continued)				
1996	2.844	.161	.380	4.693	8.079
1997	2.844	.161	.380	4.693	8.078
1998	2.987	.161	.380	4.693	8.220
1999	3.002	.160	.380	4.717	8.259
2000	3.145	.160	.380	4.717	8.402
	Scenario $T_3D_1E_1$				
1976	1.353	2.778	6.267	3.834	14.232
1977	1.353	2.750	6.201	3.834	14.137
1978	1.466	2.721	6.144	3.834	14.165
1979	1.513	2.170	4.880	3.956	12.519
1980	1.669	1.701	3.831	3.935	11.137
1981	1.709	1.323	2.977	4.029	10.039
1982	1.750	1.015	2.278	4.124	9.167
1983	1.907	.748	1.679	4.068	8.402
1984	1.950	.564	1.269	4.160	7.943
1985	1.972	.443	.995	4.206	7.615
1986	2.138	.363	.813	4.142	7.455
1987	2.161	.302	.677	4.186	7.326
1988	2.332	.261	.586	4.253	7.433
1989	2.344	.241	.538	4.137	7.260
1990	2.369	.220	.491	4.180	7.260
1991	2.521	.199	.445	4.202	7.367
1992	2.534	.180	.400	4.083	7.196
1993	2.534	.160	.356	4.083	7.132
1994	2.688	.140	.313	4.103	7.245
1995	2.688	.139	.309	3.962	7.099
1996	2.844	.137	.305	3.982	7.269
1997	2.844	.136	.302	3.840	7.121
1998	2.844	.134	.298	3.840	7.116
1999	3.002	.133	.294	3.859	7.288
2000	3.002	.131	.290	3.716	7.139
	Scenario $T_1D_2E_1$				
1976	1.334	2.801	6.318	3.779	14.232
1977	1.334	2.810	6.347	3.891	14.382
1978	1.445	2.820	6.376	3.891	14.531
1979	1.491	2.284	5.171	4.015	12.961
1980	1.528	1.851	4.187	4.114	11.679
1981	1.685	1.477	3.345	4.213	10.720
1982	1.725	1.232	2.784	4.435	10.176
1983	1.755	1.066	2.411	4.512	9.743
1984	1.794	1.091	2.470	4.614	9.968
1985	1.944	1.223	2.773	4.665	10.604
1986	1.975	1.636	3.713	4.741	12.065
1987	1.997	2.224	5.054	4.792	14.067
1988	2.164	3.077	6.998	4.868	17.106
1989	2.175	4.034	9.156	5.030	20.395

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Table H-3. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
	Scenario $T_1D_2E_1$ (Continued)				
1990	2.198	5.054	11.482	5.082	23.816
1991	2.347	6.036	13.727	5.108	27.219
1992	2.359	6.958	15.841	5.135	30.293
1993	2.359	7.842	17.871	5.135	33.207
1994	2.371	8.621	19.665	5.161	35.818
1995	2.511	9.276	21.068	5.300	38.105
1996	2.523	9.822	22.380	5.327	40.052
1997	2.523	10.145	23.138	5.327	41.134
1998	2.664	10.582	24.160	5.327	42.733
1999	2.677	10.864	24.929	5.354	43.825
2000	2.677	11.034	25.240	5.354	44.306
	Scenario $T_2D_2E_1$				
1976	1.334	2.801	6.318	3.779	14.232
1977	1.334	2.791	6.318	3.891	14.334
1978	1.445	2.791	6.318	3.779	14.334
1979	1.491	2.246	5.101	3.900	12.738
1980	1.645	1.607	4.119	3.996	11.567
1981	1.685	1.437	3.276	4.092	10.491
1982	1.725	1.187	2.714	4.189	9.815
1983	1.880	1.023	2.340	4.261	9.504
1984	1.922	1.040	2.387	4.357	9.706
1985	2.073	1.158	2.668	4.405	10.304
1986	2.107	1.544	3.557	4.478	11.686
1987	2.130	2.086	4.821	4.526	13.562
1988	2.299	2.875	6.646	4.598	16.418
1989	2.311	3.733	8.658	4.622	19.324
1990	2.472	4.661	10.811	4.670	22.615
1991	2.485	5.530	12.870	4.694	25.580
1992	2.498	6.332	14.789	4.718	28.337
1993	2.637	7.113	16.614	4.580	30.944
1994	2.650	7.767	18.206	4.603	33.226
1995	2.790	8.286	19.422	4.603	35.101
1996	2.804	8.734	20.546	4.676	36.710
1997	2.804	8.961	21.154	4.626	37.545
1998	2.944	9.318	21.997	4.626	38.885
1999	2.959	9.502	22.511	4.650	39.622
2000	3.100	9.620	22.792	4.650	40.162
	Scenario $T_3D_2E_1$				
1976	1.334	2.801	6.318	3.779	14.232
1977	1.334	2.772	6.251	3.779	14.137
1978	1.445	2.743	6.194	3.779	14.162
1979	1.491	2.200	4.947	3.900	12.537
1980	1.645	1.757	3.957	3.879	11.238
1981	1.685	1.383	3.113	3.972	10.153
1982	1.725	1.136	2.554	4.066	9.482

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Table H-3. (CONTINUED)

Projection Year	Bus	Taxi	Auto	HDT	Total
			Scenario $T_3 D_2 E_1$ (Continued)		
1983	1.880	.970	2.177	4.010	9.037
1984	1.922	.979	2.199	4.101	9.201
1985	1.944	1.082	2.430	4.146	9.601
1986	2.107	1.431	3.207	4.083	10.828
1987	2.130	1.918	4.295	4.126	12.470
1988	2.299	2.614	5.862	4.192	14.967
1989	2.311	3.379	7.545	4.078	17.314
1990	2.335	4.171	9.323	4.121	19.949
1991	2.485	4.907	10.962	4.142	22.496
1992	2.498	5.593	12.462	4.024	24.578
1993	2.498	6.208	13.850	4.024	26.580
1994	2.650	6.720	14.983	4.045	28.399
1995	2.650	7.111	15.808	3.906	29.475
1996	2.804	7.429	16.505	3.925	30.663
1997	2.804	7.553	16.802	3.785	30.943
1998	2.804	7.754	17.238	3.785	31.581
1999	2.959	7.867	17.437	3.804	32.067
2000	2.959	7.862	17.413	3.663	31.897

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